UTILIZATION OF MODIFIED WOOD SHAVINGS AS GROWING MEDIA FOR SELECTED HORTICULTURAL CROPS

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Plant production in soilless systems is attracting increased interest day by day. The major reason for these interest is the fact that soilless medium can help to eliminate soil-borne diseases and give an understanding of plant nutritional requirements. The aim of this thesis is to evaluate the suitability of chemically and physically modified wood shavings as growing media for horticultural crop production.

Five different wood shavings derived from Scots pine trees, namely untreated wood, heat treated wood, organic acid treated wood, Q-Treat, Q-Treat and organic acid treated wood, along with mixtures of peat and Q-Treat as 50/50 v/v (P50Q50), 25/75 (v/v) (P25Q75) and peat (control) were used. In order to assess the characteristics of the growing media phytotoxicity, pH, water holding capacity, N immobilization, EC, water content of the substrates were analysed. Plant performances on the substrates was evaluated by observing the vegetative and generative growth of *Hosta* 'Golden Tiara' and strawberry 'Elsanta' plants.

Q-Treat, organic acid treated wood and P50Q50 showed a high water holding capacity. No nitrogen immobilization was observed in Q-Treat. At the same time, EC and water content of the substrates were favourable for both *Hosta* 'Golden Tiara' and strawberry production. Hosta 'Golden Tiara' plants grew satisfactorily on all the substrates but the visual quality of the plants was unacceptable on untreated wood. For strawberry, vegetative growth was strong on peat and P50Q50. Least runners were formed on P25Q75 and all of the wood substrates. However, the yield from strawberries was highest on peat and P25Q75. The quality of strawberry fruits on wood substrates was equal to that on peat.

In conclusion, based on the results obtained in this experiment, 50% of peat may be replaced by 50% Q-Treat in soilless cultivation for *Hosta* 'Golden Tiara' and 75% of peat may be replaced by Q-Treat in soilless strawberry production.

Avainsanat — Nyckelord — Keywords

Soilless growing medium, wood shavings, peat, *Hosta* 'Golden Tiara', strawberry

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ABBREVIATIONS

C/N	Carbon to nitrogen ratio
d	Day
EC	Electrical conductivity
g	Gram
h	Hour
l	Litre
kg	Kilogram
M	Molar
ml	Millilitre
mg	Milligram
mS/cm	Micro Siemens per centimetre
N	Nitrogen
OM	Organic matter
Q-Treat	Brand name of Stora Enso Wood Products Oy Ltd., Finland for sodium silicate treated wood
SD	Standard deviation
v	Volume
°C	Degree Celsius

1 INTRODUCTION

Soil and soilless growing media have been used in horticultural crop production for a long time. Plant production in soilless systems is attracting increased interest day by day. The major reason for this interest is the fact that soilless media can help to eliminate soil-borne diseases and to provide an understanding of a plant's nutritional requirements. Now a days, soilless media draw attention due to its greater production of crops, high quality and early production when market price is high, and reduced energy consumption (Cantliffe et al. 2007, Cecatto et al. 2013).

Soilless growing media can be divided into two types: organic components and inorganic components. Peat, coir, wood products (derived from pine, and willow) and compost (e.g. green waste, biowaste, onion, grape and orange peels, straw and pepper plants) rice straw and biomass plant products are used as organic growing media, while sand, tuff, pumice, perlite, vermiculite, expanded clay granules, zeolite, stonewool, glasswool, and polyester are used as inorganic growing media (Belal et al. 2010, Olle et al. 2012).

Peat has been extensively used as a soilless medium for nursery and greenhouse plant production; however, it is very slowly renewable, and is expensive. Recently, renewable wood products have been attracting increased public and scientific attention due to the scarcity of natural resources and environmental concerns have arisen from the use of peat as growing medium (Zhang et al. 2013). Renewable wood products derived from pine trees are a potential source of soilless substrates for nursery and greenhouse production (Wright & Browder 2005, Fain et al. 2008, Atland 2010). Sawdust and wood fibre have been used as growing medium components in Australia, Canada, New Zealand and the Pacific coast of The United States (Prasad 1980, Raviv & Lieth 2008).

Modified wood products are increasingly utilized for instance in construction and in different outdoor applications. The wood modification methods aim at improving certain wood properties, such as the resistance against fungi and the dimensional and shape stability. The most common wood modification methods are heat, acetylation, furfurylation, melamine resin, silicone, oil/wax, and chitosan (Reeta Stöd, Stora Enso Finland, email message to author, 10 April, 2014). Due to chemicals used, these by-products can not be composted or burned. The environmental aspects, changed material properties, and the chemicals used in modification encourage the producers of modified wood to find new end uses for the by-products, such as the planer shavings, and to promote their recyclability before the final composting or burning.

This study was undertaken to evaluate the suitability of wood shavings from chemically and physically modified wood products as growing media in soilless cultivation.

2. REVIEW OF LITERATURE

2.1 Growing media in horticultural crop production

Raviv et al. (1986) assumed that pathogen free reproducible growing media was a basic requirement of modern agriculture for healthy and uniform plant production. Gorbe and Calatayud (2010) indicated that the success of soilless culture depends on nutrient solution and substrates. Alternative to peat was desired for having pathogen free and environmentally friendly plant production system. Soil and soilless growing media have been used for horticultural crop production. Soilless growing media may consist of organic components and inorganic components due to their considerable advantages. Peat, coconut coir, wood products and compost (e.g. green waste, bio-waste, onion, grape and orange peels, straw and pepper plant) are may be used as organic growing media whereas sand, tuff, perlite, vermiculite, expanded clay granules, zeolite, stonewool and glasswool, polyester may be used as inorganic growing media for horticultural plant production (Raviv & Lieth 2008). However, its need different fertigation, irrigation, management practices according to the characteristics of substrates, plant species, and climatic condition (Cantliffe et al. 2003). Olle et al. (2012) stated that interest in the use of mixture of inorganic and organic materials had been increasing in horticultural crop production practices. They also stated that the success of soilless crop production depends on the nutrient solution and the substrate condition.

Belal et al. (2010) observed that high quality of ornamental plant production was possible in rice straw residues instead of coconut coir and vermiculite mixture. The authors further stated that coconut coir and vermiculite may be used as a favourable growing medium for ornamental plant production with low cost. Tomato grow successfully in mineral wool substrates (Graham et al. 2012). Waste paper of municipal wastes are also used for horticultural plant production and it would have been an alternative of peat after composting (Molitor & Bruckner 1997).

2.1.1 Peat

Peat is formed by slow decomposition of mosses such as sphagnum moss. Peat moss is used as the main organic component of growing media for its relative homogeneity and excellent physical and chemical properties (Raviv et al. 2005, Raviv & Lieth 2008). Cation exchange capacity 206.4 cmol (+) /kg and organic matter contents (95.0%) of substrates are high in peat moss which indicated that peat had a good capacity to accumulate nutrients in plants (Sahin et al. 2002, Lopez-Galarza et al. 2003, Vaughn et al. 2011). However, low bulk density (0.086 g/cm^3) are found in peat moss (Sahin et al. 2002). pH value of raw peat from 3.5 to 4.1 and the quantity of available nutrients of peat is very low. When physiochemical properties of growth media are evaluated, EC of the peat was found 0.32 (mS/cm) and pH was found 5.83 (Martínez et al. 2013). The highest electrical conductivity is 1.065 dS/m in peat. However, Belda et al. (2013) indicated that pH could be increased by adding right amount of lime depending on plant requirement. For instance, C/N (62:1), pH (6.58), EC (0.38 dS/m), organic matter (84.1) and P (1522 mg/kg) have been obtained from peat. Low bulk density (113-290 g/L) and high porosity (14-23.4 –Kpa/V) of peat enhanced root growth of plants (Raviv & Lieth. 2008). For example, the root growth of bean seedlings are affected when the porosities of substrates are below 12 % (Prasad & Maher 2004). Vaughn et al. (2011) observed that peat had favourable physical properties like pore space, water holding capacity, bulk density for plant production. However, these physiochemical properties of peat are not suitable for all types of plant species and sometimes it have been changed due to irrigation practices (Heiskanen 1995). That is why, peat mixing substrates and substitutes of peat have been growing interest (Cantliffe et al. 2007).

2.1.2 Wood based substrates

Softwood bark, saw dust, various types of wood products possessed good physical properties by considering their low cost and favourable characteristics for plant production (Cantliffe et al. 2003, Raviv 2005, Lu et al. 2006, Altieri et al. 2014). Recently, wood based substrates have been grown interest to growers for greenhouse crop production as viable and renewable substitutes to peat, where pine trees are mostly used as a substrate mixing with peat. Pine (*Pinus spp*.) bark is a low cost easily available by-product of wood industry. The cost of pine bark is US$ 8 per m^3 which is less than the peat mixes cost of US$55 per m^3 (Cantlife et al. 2003). Several studies are performed on the application of wood products as a plant growing media (Olayinka et.al. 1985, Ortega et al. 1996, Cantliffe et al. 2007). Sahin et al. (2002) conducted an experiment on physiochemical properties of various types of substrates, where they found that higher amount of macrospores (>100 mm) and high percentages of water retention (60%) are found in sawdust than composted media. High amount of macrospores of sawdust specifies high air space (56.9 %), which enhances root growth of plant. EC of saw dust usually is low (0.15-1.3) (Raviv & Lieth 2008) and it may be increased by adding additional fertilization (Belda et al. 2013).

Mass and Adamson (1975) suggested that un-composted sawdust was not suitable due to its phytotoxicity. However, the phytotoxicity effect of wood substrates can be removed by hot water treatment. Different horticultural species are used for phytotoxicity bioassay of forestry wastes to observe plant behaviour in real growing conditions (Ortega et al. 1996). The behaviour of wood chips may vary according to different wood treatment methods and on plant species. In our best knowledge, no studies have been published or studies in wood-shavings.

Cantliffe et al. (2007) used pine bark as a soilless medium in production of strawberry and found positive performance on it. It is also observed that the yield of strawberry was different in various substrates due to different nitrogen content (Cantliffe et al. 2003). On the contrary, untreated wood chips reduce the strawberry yields and nutrient contents while use as soil mulch (Olayinka et al.1985). Sawdust could be potential alternative to peat moss media for cucumber seedling production (Sawan et al. 1999).

Wood fiber and white peat substrates perform equally in tomato growth and quality (Gruda & Schnitzler 2004). Moreover, sawdust is generally used as mulch components of high bush blueberry production, which increased leaf nutrients (Larco et al. 2013). Gruda (2009) observed that N immobilization was found in wood fibres substrates which enhanced nitrogen deficiency, and to overcome this deficiency additional N was suggested. Prasad (1980) found that sawdust had a high percentage of air filled porosity and a low content of available water. Equal or better growth of plant is found in the wood substrates compared to peat, however water holding capacity of wood substrates was lower than peat. Consequently, minor amounts of irrigation in regular interval is recommended in wood based substrates (Bohne 2004).

2.1.3 Other soilless substrates

The coir, bark, sawdust and other plant wastes and animal manures are used as growing media, which suppresses soil borne diseases (Raviv et al. 1986). Biosolids and wood wastes, and crude oilcakes are frequently used in soilless culture, though some limitations like salinity, residual phytotoxicity, high pH, N immobilization and substrate shrinkage are found in these growing media (Ravia & Lieth 2008). However, phytotoxicity could be overcome by aerobic composting process and plant pathogens and weed seeds could also be eradicated through thermal treatment process (Raviv et al. 2005). Hundreds of substrates derived from raw or composted by-product are used successfully in nursery production system. Municipal waste composts, sand and perlite, waxed cardboard, paper mill waste, turkey litter composts, spent mushroom compost, apple pomace, wood chips from pallets, pulverized glass and various types of tree barks have been revealed as acceptable growing media (Chong 2005). These substrates are vastly used in horticultural plant production for their suitable physiochemical properties (EC, pH, organic matter content, pore space) (Sahin et al. 2002). Waste papers could also be used as a substrates for plant production after composting (Molitor & Bruckner 1997).

The coir is light to dark brown, high in sodium, potassium and pH and small in amount of nitrogen. Meerow (1997) and Arenas et al. (2002) found that coir and perlite mix

(1:1/v:v) gave larger root system than those of which grown in peat and perlite with same volume mixture. Better growth rate of crisp-head lettuce is found when it was

grown on zeolite (Gül et al. 2005). Tomato grown on coconut coir dust with 20% vermin-compost show higher vegetative growth and yield (Mokhtari et al. 2013). Higher yield of various vegetables were found on different soilless growth media compared to those grown in the soil (Olle et al. 2012). Cantliffe et al. (2003) found that cucurbit crops gave better yield when grown on coarse perlite, medium perlite and pine bark in greenhouse. Guzman-Pfeiffer and Ulrichs (2011) observed high yield and quality of lettuce (*Lactuca sativa*) grown on the soilless substrates mixing rice husk, sand, saw dust and gravel with different ratio. Lettuce and tomato are grown well in organic floating system (Bilalis et al. 2009). Moreover, dairy manure compost, vermi-compost, coconut coir can be used as substrate components for organic production of lettuce seedlings (Riberiro et al. 2013). Castor bean (*Ricinus communis*) fruit husk could be used as substrate for growing fishtail palm (*Caryota spp.*) seedlings (Mendes et al. 2013). Agricultural and agro-industrial bi-products (wine, olive oil production, etc.) could increase compost value and quality of any substrate (Moral et al. 2013). Bustamante et al. (2008) found that physical properties of compost and peat mixing compost are better for plant production. These researchers examined that physical properties are different in different substrates. According to their research, in case of compost, pH was 8.2, EC was 1.96 (dS/cm), OM % was 73.9 and C/N was 16.6; composts substrate showed 100 % seed germination in lettuce and 92 % in broccoli. However, when peat is mixed with compost, the physiochemical properties are little bit differed compared to peat which has pH 7.7, EC 2.24 (dS/m), OM content 82.6% and C/N 26.3. Seed germination percentages in this substrates are 95 % in lettuce and 92 % in broccoli. Due to this different physiochemical properties, seed germination show some small differences. Another research established that composted green waste materials and combination of peat-based medium act as an potential control method for damping off disease *(Rhizoctonia solani*) in lettuce production (Doyle et al. 2013).

Favourable physiochemical properties like pH, EC and nutrient availability are observed in tea wastes along with rice husk, tree bark + rice husk and peat + perlite (El-Naggar et al. 2009, Abouzari 2012). However, Zhang et al. (2013) conducted an experiment with ornamental crops in greenhouse where physical and chemical characteristics of growing media and plant growth were best in 30 % peat + 70 % composted green waste and better in 100 % composted green waste than 100 % peat.

2.2 Growing media in *Hosta* production

Hosta spp. is a herbaceous perennial plants belonging to the Asparagaceae family. *Hosta* is a genus of plant, which includes more than 40 species (Aden 1992) originating from northeast Asia (Maekawa & Kaneka 1968, Schmid 1991). *Hosta '*Golden Tiara' is an important plant for landscape horticulture. Moreover, its leaves are used for flower arrangements (Cabrera et al. 2012). Among many herbaceous ornamental plants, *Hosta* spp. has been potentially grown for landscaping for its beautiful foliage, abounded varieties, cold resistance, perennial, first and shade growth nature (Tuhkanen et al. 2013). Juhanoja and Tuhkanen (2010) found that suitable herbaceous perennial plants were essential for urban landscaping. In Finland, *Hosta* are selected as most promising plant species in landscape against extreme climatic conditions (Juhanoja & Tuhkanen 2011,Tuhkanen et al. 2013). *Hosta spp.* are vastly grown in soil, rock soil, peat composted media (AHS 2014). Moreover, they are grown on any fertile, moisture-retentive garden soil, but addition of thin sands and heavy clays were suggested. *Hostas* are usually grown on rich organic soil composted soil. The optimal pH range for *Hosta spp*. is 6.5 to 7.5, which is slightly acidic and slightly alkaline (Heinke & Martin 2001) and the EC value is1.3-4 dS/m (Cabrera et al. 2012). The mixture of compost, peat and vermi-composts in greenhouse improve germination and growth of ornamental plants (Belda et al. 2013). However, Cabrera et al. (2012) conducted an experiment on *Hosta spp.* where they were grown on mixture of course and fine black lava residues. Most of compost provides vigorous vegetative growth and overall crop performance of ornamental plants (Olle et al. 2012).

Better vegetative growth are found in low EC (2 dS/m) but commercially acceptable flowering stem are produced in high EC (7 dS /m) in ornamental plant of *Lisianthus* 'Pure white' (Valdez-Aguilar et al. 2013). Horticultural substrates amended with peat and perlite are broadly used for production of ornamental plants like gerbera, lily, rose, pot plants and carnation (Lopez et al. 2008). In *Bougainvillea* production, the better ornamental performance are found by using the compost-based growing media compared to peat (Vecchietti et al. 2013). Moreover, biofuel crops like willow, pine bark, switchgrass, miscanthus, corn and stover were used as a substrate for successful production of ornamental plants (Altland 2010). Furthermore, ornamental plants are successfully propagated in whole pine tree substrates alone or with the combination of peat moss (Witcher et al. 2014).

2.3 Growing media in strawberry production

Strawberry (*Fragaria × ananassa* Duch.) is widely grown throughout the world in greenhouse and open field. Garden strawberry production was 4.6 million ton in 244 000 ha areas (2011) (FAOSTAT 2013). Strawberry cultivation was generally found in soil as a conventional method in open field where some environmental and phytosanitary problem is found (Cantliffe et al. 2007, Cecatto et al. 2013). Strawberry is extensively grown on soil, organic and inorganic soilless substrates or mixing of different substrates (Ayesha et al. 2011). In temperate regions, strawberries are widely grown in greenhouse under soilless cultivation (Cantliffe et al. 2007).Vegetative growth, flower induction, berry production, yield potential and timing of harvest in strawberry were affected by different substrates (Neri et al. 2012). Higher number of leaves and runners production are found in peat (Tagliavini et al. 2005) while the substrate of rock wool produce lower vegetative growth with early and less amount of berry (Neri et al. 2012). In contrast, early and high amount of flowering is delivered in sand substrates with lower number of fruits compared to peat, perlite, coco coir or amended substrates (Neri et al. 2012).

Strawberry plants are also grown successfully in composted olive mill waste for its high nutrients and economically sustainable nature (Altieri et al. 2014). In northern Europe, strawberry cultivation is widely practiced on almost 15000 ha, within this around 10 ha in soilless culture to maximize the harvest period and to get early marketable berry (Neri et al. 2012).

Strawberry give positive yield response when grown on media with greater percentage of peat (Cantliffe et al. 2003). However, good yield and quality of strawberries are found in perlite and pine bark substrates. Strawberries have shallow root system, large leaf area and fruits with high water content 92.68 (g/100g fresh weight) (De Souza et al. 2014), which needs high water requirement. Sudden and severe water stress are found in soilless substrates for strawberry production due to the inadequacy of irrigation (Klamkowski et al. 2006). Highest vegetative growth and yield of strawberry plant is

found for substrates with water content of 25-34 % and water holding capacity of substrates is 74-100 % (Latigui et al. 2011, Klamkowski et al. 2006). The pH and EC range for favourable nutrients of strawberry substrates are 5.5-6.5 and 1.3-3.8 respectively (Latigui et al. 2011). Physical and chemical properties like air filled porosity, moisture content, bulk density, pH, electrical conductivity and nutrients of substrates are closely related with the growth, yield and quality of strawberry plant (Ayesha et al. 2011, Latigui et al. 2011). These researchers also found that coconut coir improved berry quality by increasing ascorbic acid and sugar content. Kuisma (2013) conducted an experiment of strawberry on peat, coir, plant fibre, and peat and plant fibre mixes substrates where strongest vegetative growth was found in peat compared to other substrates, however yield and quality of strawberry among the substrates were found nearly similar.

3 RESEARCH OBJECTIVES

The research was conducted with the following objectives:

a) To evaluate the effects of five different types of modified and unmodified wood-shavings, and peat as a growing medium on growth and development (vegetative and generative) of horticultural crop species i.e. *Hosta* ‘Golden Tiara’ and strawberry ‘Elsanta’.

b) To determine whether the performance of *Hosta* ‘Golden Tiara’ and strawberry on these wood-based media are equal to or better than when grown on peat.

c) To observe the effects of possible phytotoxic phenolic compounds of wood-based growing media on tomato and lettuce through the phytotoxicity.

4 MATERIALS AND METHODS

Five types of planer shavings from chemically and/or physically modified wood products were obtained from Stora Enso Wood Products Oy Ltd. (Finland) and unfertilized sphagnum peat collected from Kekkilä (Vantaa, Finland) was used as control. The wood substrates were:

1) Untreated wood (U)
2) Heat treated wood (H)
3) Organic acid treated wood (OA)
4) Q-Treat (Q)
5) Q-Treat and organic acid treated wood (Q+OA)

Wood shavings were produced by planing Scots pine (*Pinus sylvestris* L.) sawn timber. Before planing, sawn timber was modified chemically and/or thermally. Heat treated wood (ThermoWood® 2013) were treated at 190-212 °C. Q-Treat products were treated with a natural sodium silicate solution before mild heat treatment (Stora Enso Wood Products Oy Ltd. 2014). Q-Treat is a brand name of Stora Enso, and the Q-Treat product family includes a variety of solutions for different end use applications. Organic acid treated wood products were heat treated at low temperatures after mild acid treatment.

The work was divided into four parts:

1) Phytotoxicity
2) Characteristics of growing media
3) Cultivation of *Hosta* ‘Golden Tiara’ and
4) Observation of strawberry production

This research work was conducted from 14 June 2013 to 7 January 2014 at greenhouses and laboratories of University of Helsinki,Viikki campus (Southern Finland, 60°22´ N, 25°02 E). One sub-compartment of the greenhouse was chosen for growing lettuce, tomato and strawberry, and outdoor site of greenhouse was chosen to grow *Hosta* ‘Golden Tiara’.

4.1 Phytotoxicity

4.1.1 Growing media preparation

Eleven types of substrates were used in the phytotoxicity bioassay on tomato and lettuce. Woody materials were washed in order to remove phenolic compounds from the materials. The wood materials, which undergone test were: Q-Treat (Q), heat treated (H), organic acid treated (OA), Q-Treat+organic acid treated (Q+OA), untreated (U), unfertilized peat (Peat) (Keikkilä Oy, Vantaa, Finland) was used as a control. In addition woody materials were washed and these washed materials were also included in this experiment. The washed media were washed Q-Treat (washed Q), washed heat treated wood (washed H), washed organic acid treated wood (washed OA), washed Q-Treat+organic acid treated wood (washed Q + OA), washed untreated wood (washed U).

Washing procedure of the substrate was performed to remove the phenolic compounds of wood materials which was then followed for phytotoxicity assay. At first, 65 $^{\circ}$C hot water was taken in a big bucket. A total of 20 l of each wood product was soaked in hot water bucket and mixed by a stick for 10 minutes. After 10 minutes, the substrate was placed on a net cloth in the water basin, and tap hot water (at 45 $^{\circ}$C) was used for rinsing the washed substrates. Then all of the substrates were drained for 1 hour.

4.1.2 Experimental design

One-litre pots were used for this experiment. The pots were marked and a piece of paper was placed into the pot before adding substrates. All the pots were watered before sowing of seeds. Tomato (*Solanum lycopersicum)* cv Tanskan Vienti and lettuce (*Lactuca sativa)* cv Great Lakes seeds were collected from Siemen, Helsinki. Two tables were used for placing the pots in the greenhouse. For each of 11 treatments (Six substrates and five washed substrates) ten replicates of each species were used (110 for tomato, 110 lettuce seedlings). Plant to plant and row to row distances were 30.5 cm and 30 cm, respectively for both tables. The pots were also re-randomized once a week to minimize border effect. After sowing seeds, plastic cover was used for covering the seed pots to reduce the evapotranspiration. Pots were manually irrigated once a day during the period of four weeks. No fertilizer used in this phytotoxicity assay.

4.1.3 Observations

The aim of the observations was to evaluate the germination percentage, and dry weight of lettuce and tomato seedlings. Germination was recorded by counting the seedlings twice a week. Dry weight was measured after 30 days of sowing by drying in the oven (Memmert, Schwabach, Germany) at 75 $^{\circ}$C for 2 d and root length was measured by a scale. At the last phase of the experiment, pH of substrates was measured from leaching water of growing media by a pH meter (Ultrabasic, Denver instrument, Gottingen. Germany). EC and water content of the substrates were determined by WCM-H meter (Grodan, Roermond, the Netherlands).

4.2 Characteristics of substrates

Characteristics of the substrates were determined by measuring of pH, water holding capacity (WHC) and by inorganic nitrogen content test.

4.2.1 pH

pH was determined for the selected substrates i.e. Q-Treat, washed Q-Treat, mixture of Q-Treat and peat (50/50 as v/v), Q-Treat+organic acid treated, heat treated wood, organic acid treated, untreated wood and unfertilized peat (White A2 640 W, Kekkilä,Vantaa, Finland).Three replicate samples for each substrate were measured. Samples of 1 l were soaked in 2 l water. After two hours, the substrates were squeezed by hand, and leachate was collected into a small pot for pH analysis. The preliminary pH of leaching water was measured by pH meter (Ultrabasic, Denver instrument, Gottingen, Germany). The range of pH was 3.0 to 6.8 where the lowest was heat treated wood (3.0) and the highest one was Q-Treat wood (Table 1). As heat treated wood, organic acid treated wood, and untreated wood, as well as peat had lower pH than the ideal pH range for *Hosta spp*. which is 6.5 to 7.5 (Heinke & Martin. 2001). Therefore, $CaCo_3$ (Kekkilä,Vantaa) was added for increasing the pH of the substrates. An experiment was also conducted to find out the optimal amount of $CaCo_3$. Either 0.33 mg $CaCo_3$/1 l substrate (Heat treated wood, organic acid treated wood, untreated wood and peat) or 0.74 mg $CaCo_3$/1 l substrate (Heat treated wood, organic acid treated wood and untreated wood) was added 1d of incubation, the pH of leaching water of the substrates was measured.

Table 1. pH adjustment of growing media of *Hosta* 'Golden Tiara' cultivation

Substrate	Initial pH	pH (after adding 0.33mg $CaCo_3$/kg)	pH (after adding 0.74mg $CaCo_3$/kg)
Q-Treat	6.8		
Washed Q-Treat	6.4		
Q-Treat+ peat	5.1	6.8a)	
Q-Treat+OA treated wood	6.5		
Heat treated wood	3.0	6.5	6.8
OA treated wood	4.6	5.9	6.8
Untreated wood	5.9	6.8	7.2
Peat	4.2	6.8	

a)pH (adding 0.33 mg $CaCo_3$/kg peat)

On the basis of the results (Table 1) we decided to add 0.33 mg $CaCo_3$/ kg for untreated wood and peat substrates and 0.74 mg $CaCo_3$/kg for heat and organic acid treated wood substrate.

4.2.2 Water holding capacity of the substrates

The water holding capacity of eight substrates was measured:
Q-Treat (Q), washed Q-Treat (Washed Q), heat treated wood (H), organic acid treated wood (OA), Q-Treat+organic acid treated wood (Q+ OA), untreated wood (U), mixture of Q-Treat and peat 50/50 as v/v (P50Q50) and peat as a control.

The substrates (35g each) were dried in the oven (Memmert, Schwabach, Germany) at 73 °C for three days. After drying, these were weighed and 30g of each sample was then taken for measurement of water holding capacity. Filter paper (Whatman 18.6 cm, Macherey-Nagel, Germany) was placed inside the pot and the mass of pot and filter paper was recorded. Then 30g of each oven dry media was placed into the pot gently and the data were recorded as mass of the cup, filter paper and dry sample. The pots were placed under the tap and the samples were allowed to soak in water for 20 minutes and drained out for 15 minutes by putting a long sieved tray on the basin. The pots were placed in a room for three days with white plastic cover. The data were recorded as follows:

Mass of cup and dry filter paper (c)
Mass of cup, dry filter paper and dry sample (a)
Mass of cup, saturated filter paper and saturated sample (b)

Calculations were done by following way:

1) Mass of dry sample (x) = (a-c) g
2) Mass of saturated sample (y) = (b-c) g
3) Mass of water contained in saturated sample (z) = (y-x) g
4) Per cent water holding capacity (% WHC) = z (Mass of water contained in saturated sample)/x (Mass of dry sample) × 100

4.2.3 Inorganic nitrogen

The ratio of carbon (C) to nitrogen (N) was determined from the substrates. On the basis of C/N – ratio, the per cent of N and C mobilization was estimated. Eight substrates i.e. untreated wood (U), heat treated wood (H), organic acid treated wood (OA), Q-Treat (Q), washed Q-Treat (washed Q), Q-Treat+organic acid treated wood (Q+OA), mixture of peat and Q-Treat as 50/50 as v/v (P50Q50) and peat were used in this experiment, each substrate had four replicates (8 × 4 × 4 = 128). Total nitrogen of growing media was measured by using a Vario Elementer Max C/N analyser (Memmert, Scwabach, Germany). Samples were put in the paper bags and dried in an oven at 60 ^{o}C for two days. The dry samples were crushed and 1g substrate was taken from each sample. The results were measured as per cent of nitrogen in the analysed sample.

Inorganic nitrogen of the eight substrates was determined by incubation of the substrates without plants for two months in 0.5 l pots. Total number of samples was

160 (8 treatments × 4 replicates × 5 times = 160). The samples were kept in the sub compartment of green house. The experiment started on 31 September 2013 and ended on 31 December 2013. Samples were kept at 20 ^{o}C in greenhouse room. The samples were covered with plastic cover to keep them moist. The pots were wetted twice every week and watering was done over the surface of the growing media to compensate for any loss of water and to keep them moist all the time. The whole pots were collected at 0 week, 2 weeks, 4 weeks, 6 weeks and 8 weeks and stored at -20 ^{o}C temperatures in the cold room. Then the samples were sent to the Viljavuuspalvelu Oy (Mikkeli, Finland) to determine inorganic nitrogen.

4.3 Cultivation *of Hosta* 'Golden Tiara'

4.3.1 Plant materials and substrates

Hosta 'Golden Tiara' is an ornamental plant originated from the group of *Hosta Nakaiana.* In this experiment, we obtained *Hosta* 'Golden Tiara' small plants from Muhevoinen, Helsinki. The substrates used for *Hosta* cultivation were Q-Treat (Q), washed Q-Treat (Washed Q), heat treated (H), organic acid treated (OA) wood, Q-Treat+organic acid treated wood (Q+OA), untreated wood (U), mixture of peat and Q-Treat as 50/50 v/v (P50Q50) and unfertilized peat (P).

Forty grams slow released fertilizer (lannoite 16-3-10 (NPK),K2 GRF,Vantaa, Finland) was added to 10 l of all growing media. The wood growing media and peat were calcified by using $CaCo_3$ (Puutarhakalkki, Kekkilä, Finland) for increasing pH to with *Hosta'*s ideal pH range, which was 6.5-7.5 (Heinke & Martin 2001). The plants were transplanted on 16 June 2013 at the outdoor area of the greenhouse. The drip irrigation system was established after 14 days of transplanting. In first 14 days, irrigation was performed with manual operation once a day. Initially, 150 ml (25 ml × 6 times) of water was served to each plant daily through automatic drip irrigation system. After 15 days of first, the rate was increased to 252 ml every day (42 ml × 6 times) to each plant.

4.3.2 Experimental design

The plants were grown in 2 l pot in nine replications for eight substrates (i.e. U, OA, H, Q, Washed Q, P50Q50, Q+OA, and peat).The experiment was established in complete randomization system, where 9 replicates were used for each treatment. For 8 different substrates with 9 replicates each (8 × 9 = 72), total 72 plants were used for this experiment.

4.3.3 pH, EC and water content of growing media

The pH, EC and per cent of water content of the substrates was measured once a week during the experimental period in the substrates and in the leachate from its irrigation water and slow release fertilizers. Leaching water of substrates was collected by using a plate under each pot for measurement for EC and pH (Ultrabasic, Denver instrument, Gottingen. Germany). The EC and pH of the leachate were measured from five samples of each treatment. Electrical conductivity (EC) and water content (WC) of the substrates were determined in all pots by using WCM-H meter (Grodan, Roermond, and The Netherlands).

4.3.4 Vegetative growth

Leaf number of *Hosta* ‘Golden Tiara’ plants was counted every week after transplanting of the plants. Petiole length (cm) of the third youngest leave of the plants was observed from once a week during the experiment time. Plant height (cm) and width (cm) were measured every two weeks. Canopy volume was calculated using the formulae, volume = $\pi r^2 h/4$, where, r (cm) is the plant width and h (cm) is the plant height. These measurements were performed for all of the nine plants of each treatment (8 × 9 = total 72 plants). Root lengths of total root system were measured at the end of the experiment Canopy lengths and heights, petiole lengths and root lengths were measured by using a measuring scale. After harvesting, the plants, leaves and roots of all of the plants were washed. After that, vegetative plant parts leaves and roots separately were dried out at 73 °C for 3 d. The dry weights (g) of all of the parts were recorded by weighing the plant parts. Three plants from each treatment (3 × 8= 24 plants) were collected to measure leaf area (cm^2) at the end of the experiment to evaluate vegetative growth of *Hosta* with a portable leaf area meter (LI-3000A, LICOR, USA).

4.3.5 Generative growth

Number and heights (cm) of the inflorescences of *Hosta* 'Golden Tiara' plants were measured every two weeks. After that, the inflorescence of the plant was dried at 73 °C for 3 d. The dry weights (g) were recorded. Numbers, heights and dry weights were measured for all the plants.

4.3.6 Visual observation of plant growth

At the end of the experiment, photographs of the plant parts (leaves, inflorescence and roots) were taken by a digital camera (Cannon, Power shot A4000 16 mega pixels, China) for the visual observation of leaf and flower colour, and root development on different substrates.

4.4 Strawberry production

4.4.1 Plant materials and substrates

Garden strawberry (*Fragaria* × *ananassa* cv. Elsanta) was chosen for this experiment. The *frigo* strawberry plants of 'Elsanta' were brought from a commercial nursery (Neessen Aardbei and Aspergeplanten, Grashoek, The Netherlands). Average crown diameter of the *frigo* strawberry plants was 15-18 mm with two three small leaves. The plants were stored at -1 °C before planting.

The soilless substrates used for strawberry cultivation were Q, H, Q+ OA, P50Q50, mixture of peat 25% and Q-Treat 75% v/v (P25Q75) and peat (white A2 640, Kekkilä, Vantaa, Finland). The substrates P50Q50 and P25Q75 were prepared by mixing peat and Q-Treat in 1:1 and 1:3 ratio volumes respectively.

4.4.2 Experimental design

The experiment was established in completely randomized block design with 4 blocks and eight replicates per block. For 6 different substrates with 32 replicates in total 192 treatment plants and 62 boarder plants were used. Sixty two border plants were planted to avoid border effect. Blocks were arranged according to the sunlight conditions of greenhouse room. The wood growing media were calcified (Table 1) by using $CaCo_3$ (Puutarhakalkki, Kekkilä, Finland) for increasing pH. The pH of peat was 6.2 which is appropriate for strawberry cultivation, so peat was not calcified. The strawberry plant were transplanted on 16 September 2013 in 2 l rose pots in six different substrates greenhouse compartment. All pots were placed on the two tables of the greenhouse sub-compartment. Plant to plant distance was 26 cm and row to raw distance was 32.2 cm. The drip irrigation system was established 7 d after transplanting. During first 7 d, irrigation was performed with manual operation. When the natural day length was <16 h, the additional photoperiod (total 16 h) of the greenhouse compartment was maintained by using high pressure sodium light (HPS, 400W). Day temperature was 18 °C at the vegetative growing period but it was decreased to 15 °C during the flowering period. Night temperature was maintained at 11 °C. The experiment was finished 113 d after of transplanting.

Fertilizers (50% Yara ferticare 7-9-32 (NPK) and 50% Yara Calcinit 5-0-0 (NPK) were applied along with irrigation water and the EC of fertilizer solution was maintained at 1.3 mS/cm. Irrigation rates were changed according to water content of the substrates. When the determined water content was low, then the amount of irrigation and irrigation timing were increased.

Table 2. Irrigation regime for strawberry grown on six different substrates.

	Number of times/d	Amount of water in each time (ml/plant)	EC (mS/cm)
After transplanting(0-14 days)	3	20	1.3
During flowering (15-28 days)	4	20	1.3
During fruiting (29-42 days)	5	30	1.3
43-50 days	6	38	1.3
51-113 days	7	38	1.3

4.4.3 Substrate conditions

pH, EC of the leachate and, EC and water content of the ground of growing media were measured as described for *Hosta* 'Golden Tiara' cultivation in chapter 4.3.3.

4.4.4 Pollination and plant protection

Bumble bee (*Bombus terrestris*) hive (Syngenta Bioline, The Netherlands) was placed at a corner of the greenhouse to ensure equal and appropriate pollination of all flowers. It was placed quite high from the greenhouse floor to protect the bees from small insect and ground water. A paper shade was used to protect from direct sunlight. Sulphurization (Paskal Technologies Ltd., USA) was installed in the greenhouse compartment to protect from powdery mildew at the beginning of the experiment. At fruiting stage, some aphid insects (*Aphis gossypii)* attacked the strawberry plants, so pesticide was sprayed twice during the harvesting time (3 and 10 December, 2013). The pesticide substances were Vertimec and Confidor. Plastic nets were used to support inflorescences and developing fruits.

4.4.5 Vegetative growth

Leaf numbers and petiole lengths were measured as described for *Hosta* 'Golden Tiara' in chapter 4.3.4. The Runners were counted and removed from the plants once a month. Runners, leaves, root balls were placed in at 75 °C for 2 d and their dry weights were measured. At the end of the experiment, the roots of the strawberry plants from different treatments were cut longitudinally, and their photographs were taken for observing root volume. Two plants per treatment and from each of 4 blocks (2×6×4 = 48 plants) were collected to measure leaf area at the end of the experiment (LI-3000A portable leaf area meter). Nutrient contents (micro and macro nutrients) of the strawberry leaves were analysed at the end of the experiment by Vilkavuuspalvelu Oy (Mikkeli, Finland). For this analysis, strawberry leaves were collected and samples from two blocks were pooled. Consequently, there were two replicate samples for each treatment.

4.4.6 Yield and yield quality

Time of flowering was determined as a number of days from transplanting to the first open flower in each plant. Yield and yield quality were determined by recording the number of berries, weekly berry yield (g), total marketable berry yield (g), average berry weight (g), and dry matter content of berry.

When berry turned to fully red, the first harvest was done. First harvesting was done on 18 September, 2013 which was 64 d after transplanting. Fruits were harvested twice a week (Monday and Thursday). The duration of harvesting was 7 weeks. Dry matter content was measured two times after drying on oven at 75 ^{o}C for 3 d. Dry matter content was calculated from the total fresh yield and total dry yield according to the following equation.

$$Dry-matter-content\left(\%\right)=\frac{dry\,weight\left(g\right)}{fresh\,weight\left(g\right)}\times 100$$

Concentration of soluble solids in extracted fruit juice was measured by a refractometer (Master Refractometer Atago Co. Ltd., Tokyo, Japan) from randomly selected 5 berries from each treatment for three times, at the beginning, at the middle and at the end of the harvesting. The samples were placed inside two folded muslin cloth and squeezed by potato crusher (Zaseves, Italy). The muslin cloth was used for fine filter extracting of juice. About 1-2 drops of juice were placed on the clean and dry prism, and then reading was taken as ^{o}Brix. The amounts of titratable acid in berries were determined in a sample of extracted juice by titrating it with 0.1 M NaOH solution. 10 ml berry juice and 10 ml distilled water were added. The burette was filled with 0.1 M NaOH solution. The solution was added into the fruit juice with the presence of pH meter. The titration was continued until pH reached at 8.1. The analysis was done twice during the fruiting season from the four replicates per treatment of each block ($4 \times 6 \times 4$ = Total 96). Four replicates were chosen due to less number of berries per plant.

4.5 Statistical analysis

The experiments were set up by using completely randomized design (CRD) in case of phytotoxicity bioassay and *Hosta* 'Golden Tiara' cultivation and randomized complete block design (RCBD) for strawberry production. The data analyses were conducted using SPSS software version 21.0 (SPSS, Chicago, IL, USA). Tukey´s test were used for mean comparisons. The differences were considered statistically significant when $P \leq 0.05$. Different mean values marked with the different letters- a, b, c, d represent the significance of value differences.

5 RESULTS

5.1 Phytotoxicity

5.1.1 Germination

The lettuce and tomato seeds started germination between two and seven days after seed sowing, respectively. At least one seed per pot germinated within seven days for lettuce and 10 days for tomato, respectively. Germination percentages for both lettuce and tomato on Q-Treat (Figures 1 and 2) were significantly higher on washed substrates than on unwashed substrates. Washed and unwashed substrates were not significantly different from the rest of the substrates for either crop. Peat showed a lower percentage of germination than all of the wood substrates except washed Q, and OA (both washed and unwashed), for both tomato and lettuce.

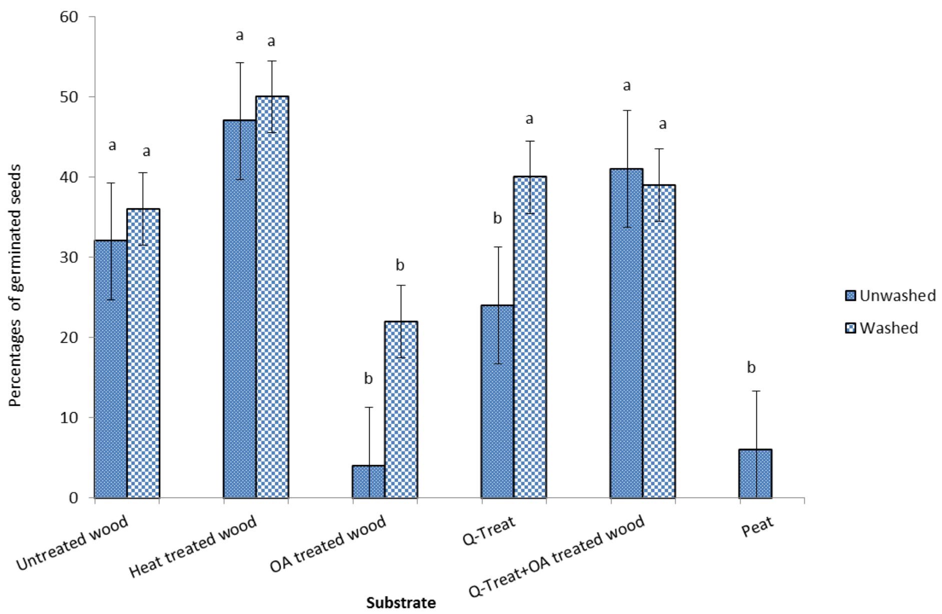


Figure 1. Seed germination percentages for lettuce on different substrates. Mean values marked with the same letters do not differ significantly ($P \leq 0.05$) in Tukey's test. Vertical bars represent ±SD (n = 10).

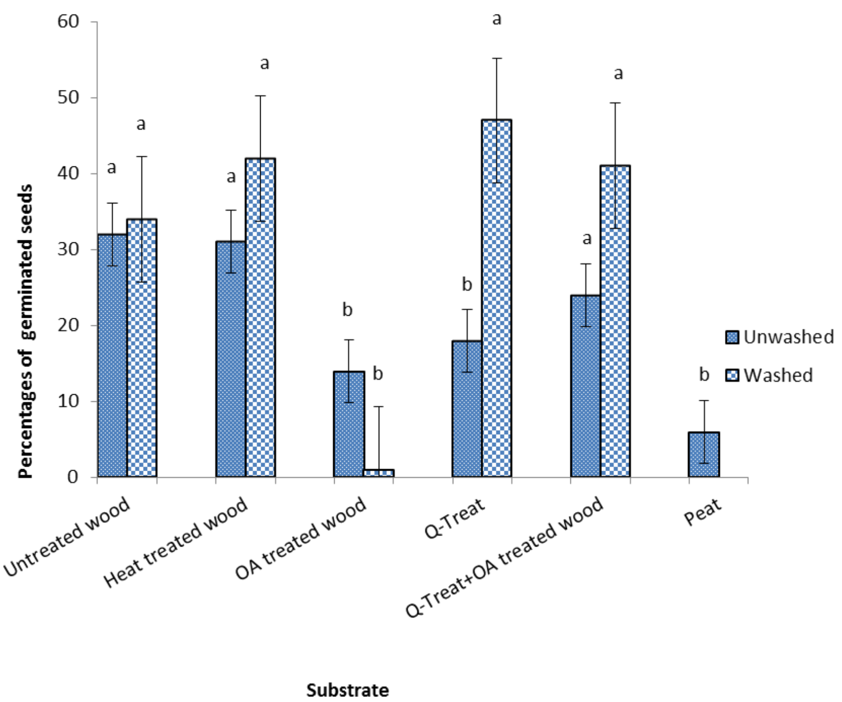


Figure 2. Seed germination percentages for tomato on different substrates. Mean values marked with the same letters do not differ significantly ($P \leq 0.05$) in Tukey's test. Vertical bars represent ±SD (n = 10).

5.1.2 Dry weight of seedlings

Peat and washed OA generally produced a lower level of dry weight than other substrates for both tomato and lettuce (Table 3). However, the dry weight of tomato seedlings was significantly lower (*P* = 0.001) on OA (washed and unwashed), washed Q+OA and peat than on other substrates. In the case of lettuce, OA, washed OA and peat substrates produced a lower dry weight than other wood substrates, and there was no significant difference between growing media. Seed germinated on peat and washed OA showed less growth and development, and consequently the lowest dry weight was observed in both species.

Table 3. Dry weights of tomato and lettuce seedlings grown on different substrates. Means followed by different letters were significantly different at $P \leq 0.05$ in Tukey's test (n = 10).

Substrate	Dry weight (g)	
	Tomato	Lettuce
Untreated wood	4.7 a	4.5 a
Washed untreated wood	4.0 a	4.5 a
Heat treated wood	4.7 a	4.6 a
Washed heat treated wood	4.7 a	4.8 a
Organic acid treated wood	2.6 b	0.0 b
Washed OA treated wood	0.0 c	0.5 b
Q-Treat	4.7 a	4.5 a
Washed Q-Treat	4.5 a	4.7 a
Q-Treat+OA treated wood	4.7 a	4.6 a
Washed Q-Treat+OA treated wood	2.2 b	4.6 a
Peat	0.7 c	0.5 b
P	0.001	0.001

5.1.3 Growing medium conditions

Peat and OA (both washed and unwashed) substrates showed a low pH (i.e. 3.3–4.0) in the leaching water, whereas Q, U, washed U, washed H, washed Q+OA and Q+OA showed a high pH (Figure 3).

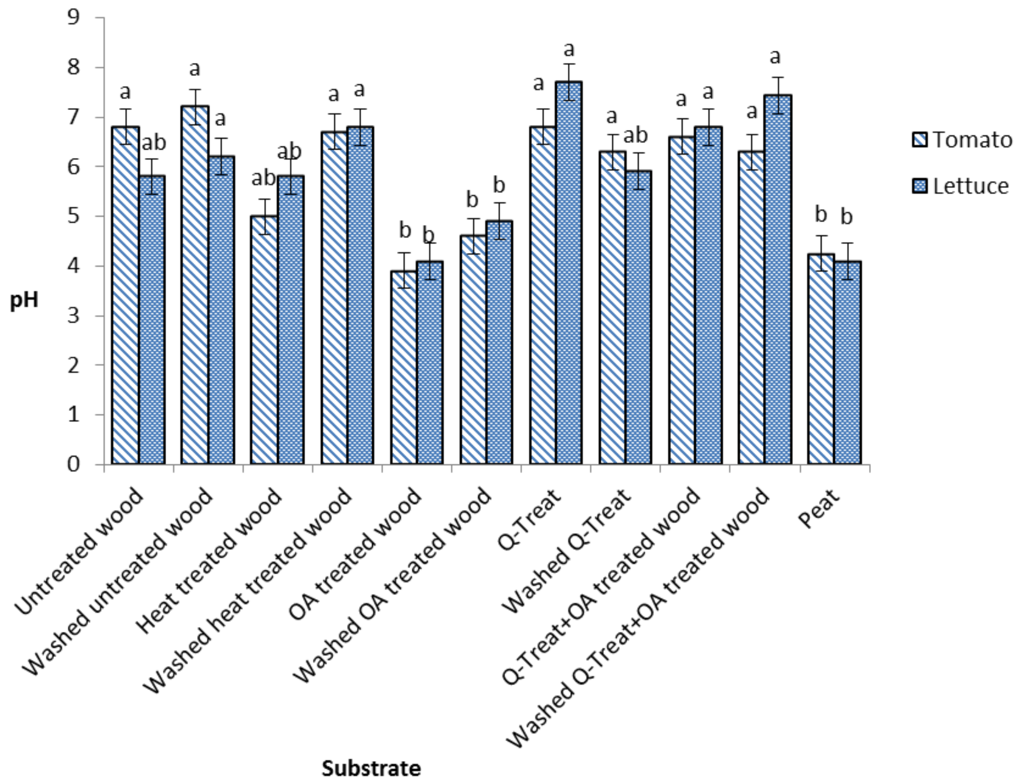


Figure 3. pH of leaching water when lettuce and tomato were grown on different substrates. Mean values marked with the same letters do not differ significantly ($P \leq 0.05$) in Tukey's test. Vertical bars present ±SD (n = 10).

Electrical conductivity (EC) (mS/cm) in the leaching water of different substrates showed significant differences ($P = 0.001$) (Figure 4). The EC of Q, and Q+OA was higher than that of U, washed U, H, washed OA, washed Q, washed Q+OA and peat for both tomato and lettuce substrates. However, washed H showed differences between tomato and lettuce species, with a high EC found in the tomatoes and a low EC in lettuce.

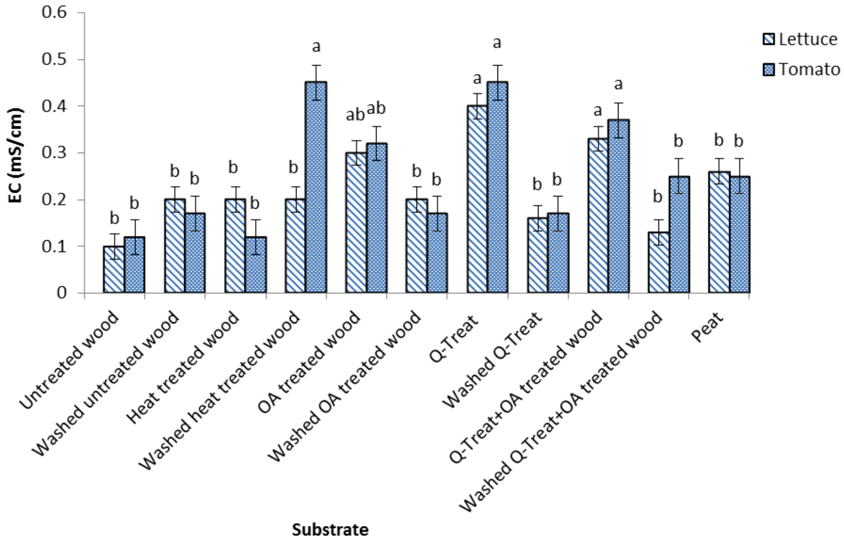


Figure 4. Electrical conductivity of leaching water when lettuce and tomato were grown on different substrates. Values marked with different letters differ significantly ($P \leq 0.05$) in Tukey's test. Vertical bars represent ±SD (n = 10).

Water content differed significantly (P = 0.003) between the substrates (Figure 5). It was high in peat, Q+OA, OA, H and low in U, washed U, washed OA, and washed Q substrates for both tomato and lettuce.

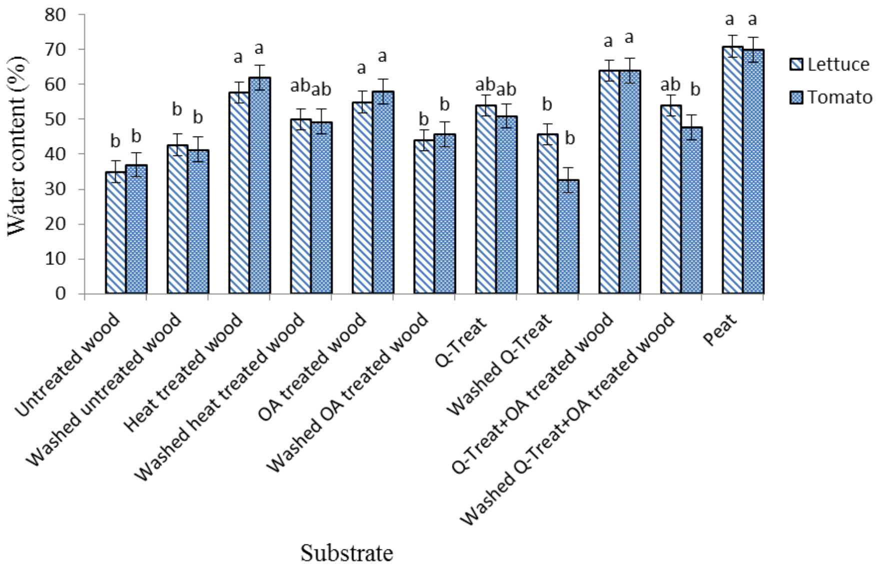


Figure 5. Water content of substrates when lettuce and tomato were grown on different substrates. Values marked with different letters differ significantly ($P \leq 0.05$) in Tukey's test. Vertical bars represent ±SD (n = 10).

5.2 Characteristics of growing media

5.2.1 Water-holding capacity

Q, OA, and P50Q50 substrates showed a higher water-holding capacity than U, Q+OA, H and washed Q (Figure 6). However, the water-holding capacity of peat did not differ significantly from any of the wood substrates.

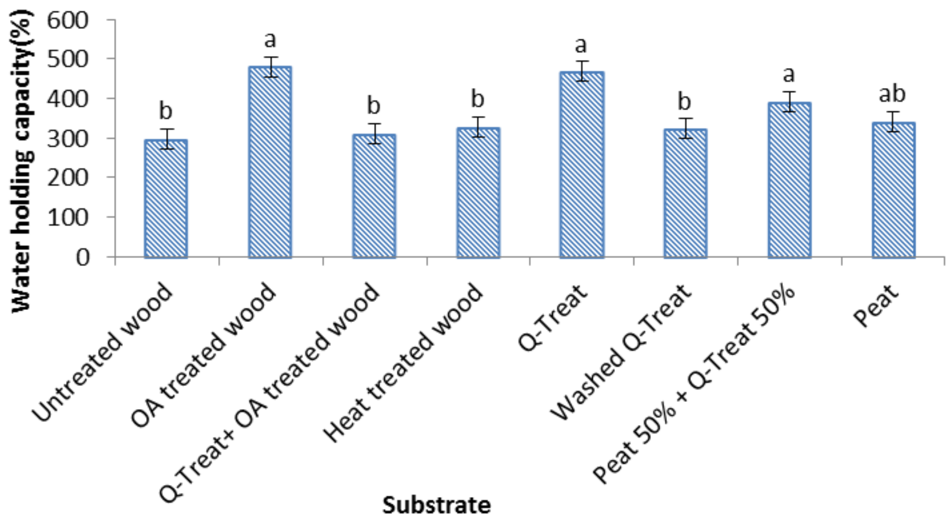


Figure 6. Water-holding capacity as a percentage of dry weight of eight different substrates. Values marked with different letters differ significantly ($P \leq 0.05$) in Tukey's test. Vertical bars represent ±SD (n = 3)

5.2.2 Inorganic nitrogen

Small amounts of nitrogen were found in the eight different substrates. A high C/N ratio was found in OA, whereas this was low in peat and Q (Table 4). Very small percentages of N and C were found in the substrates, where Q and peat had a high content of N among other substrates. The highest content of C among the substrates was found in Q and OA. Inorganic N was high in U at week 0 to week 6; however, Q was high and OA and H were low in all incubation periods (0, 2, 4, 6, and 8, Table 5). Q+OA was also high in inorganic N except for during week 0. At the end of the incubation period, N content was higher in Q and Q+OA than in the other substrates.

Table 4. The ratio of C to N, content of N, and C in different substrates. Means followed by different letters were significantly different at $P \leq 0.05$ in Tukey's test (n = 4).

Substrate	C/N	N (%)	C (%)
Untreated wood	114 b	0.003 ab	0.34 b
OA treated wood	220 a	0.002 b	0.44 a
Heat treated wood	100 b	0.003 ab	0.30 b
Q-Treat	96 c	0.005 a	0.48 a
Washed Q-Treat	149 b	0.002 b	0.30 b
Q-Treat+OA treated wood	99 b	0.003 ab	0.30 b
Peat 50%+Q-Treat 50%	168 b	0.002 b	0.34 b
Peat	60 c	0.005 a	0.30 b
P	< 0.001	0.001	<0.001

Table 5. Amount of inorganic N (%) in different substrates during 8 weeks incubation. Means followed by different letters were significantly different at $P \leq 0.05$ in Tukey's test (n = 4).

Substrate	Inorganic N (%)				
	Time (Weeks)				
	0	2	4	6	8
Untreated wood	0.003 a	0.002 a	0.002 a	0.002 a	0.000 b
OA treated wood	0.002 ab	0.001 b	0.000 c	0.000 b	0.000 b
Heat treated wood	0.001 b	0.000 c	0.000 c	0.000 b	0.000 b
Q-Treat	0.002 ab	0.002 a	0.002 a	0.002 a	0.002 a
Washed Q-Treat	0.002 ab	0.000 c	0.001 b	0.001 a	0.000 b
Q-Treat+OA treated wood	0.002 ab	0.002 a	0.002 a	0.002 a	0.002 a
Peat 50%+Q-Treat 50%	0.002 ab	0.002 a	0.002 a	0.000 b	0.000 b
Peat	0.000 ab	0.001 b	0.001 b	0.002 a	0.000 b
P	<0.001	<0.001	<0.001	<0.001	<0.001

5.3 Cultivation of *Hosta* 'Golden Tiara'

5.3.1 pH, EC and water content of growing media

Figure 7 provides information on the EC (mS/cm) of substrates (Figure 7a) and leachate (Figure 7b), pH of leachate (Figure 7c), and water content (Figure 7d) of substrates during *Hosta* 'Golden Tiara' cultivation. All the substrates and leachate had low EC values (0.1–0.3) at the very beginning of the experiment (Figures 7a and 7b). Moreover, no differences were found in the EC of substrates initially (weeks 1 to 2) but this escalated rapidly in the last phase of the experiment (weeks 6 to 9), when that of Q+OA and Q, in particular, increased dramatically (Figure 7a). At the last measurement of the substrate EC, Q+OA and Q had a higher EC value than the other substrates. However, there were no differences found in the EC value of the leachate of the substrates throughout the experiment. The observation showed that the pH of the leachate remained constant between 6 and 7 throughout the growing period, with small fluctuations (Figure 7c). The pH of the eight substrates showed no differences throughout the growing period. The peat and P50Q50 substrates showed a comparatively higher water content than the wood substrates (Figure 7d). However, at the end of the experiment, the water content of all the substrates had decreased.

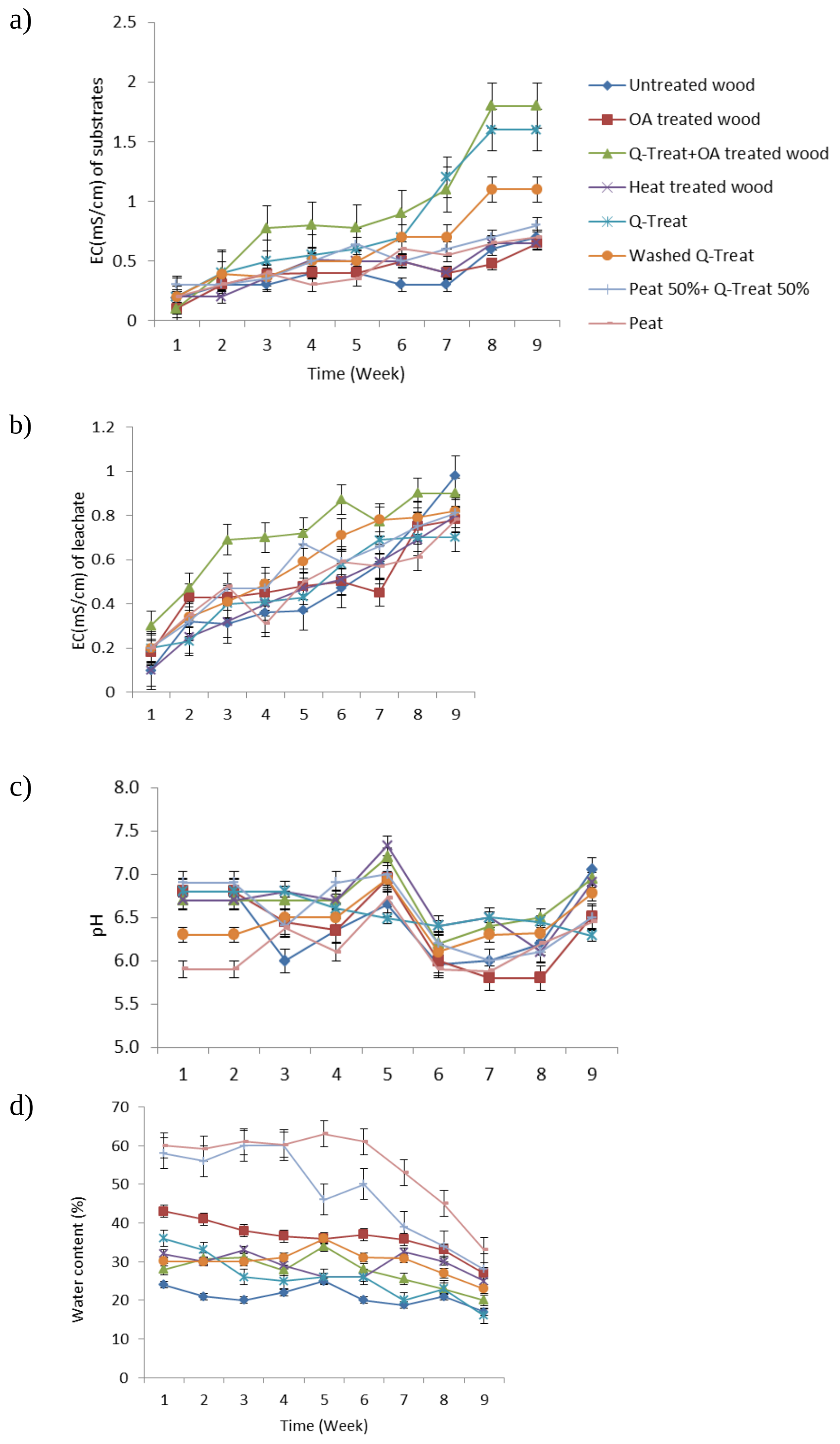


Figure 7. a) EC (mS/cm) of substrates, b) EC (mS/cm) of leachate, c) pH of leachate, and d) water content of substrates during cultivation of *Hosta* ‘Golden Tiara’. Vertical lines represent ±SD (n = 9).

5.3.2 Vegetative growth

In general, at the beginning of the experiment (weeks 0–4) there were no significant differences in the leaf number of the *Hosta* plants, but differences were found in the middle- to end-phases of the experiment (weeks 5–10) (Figure 8). The maximum number of leaves was found in the *Hosta* plants on P50Q50 (64.5) substrate and the minimum on U (28.3), OA (37.9) and H (40) substrates at week10, whereas the number of leaves on peat (49), washed Q (51.1) and Q (56.7) was significantly lower than P50Q50, but higher than on U and OA and H.

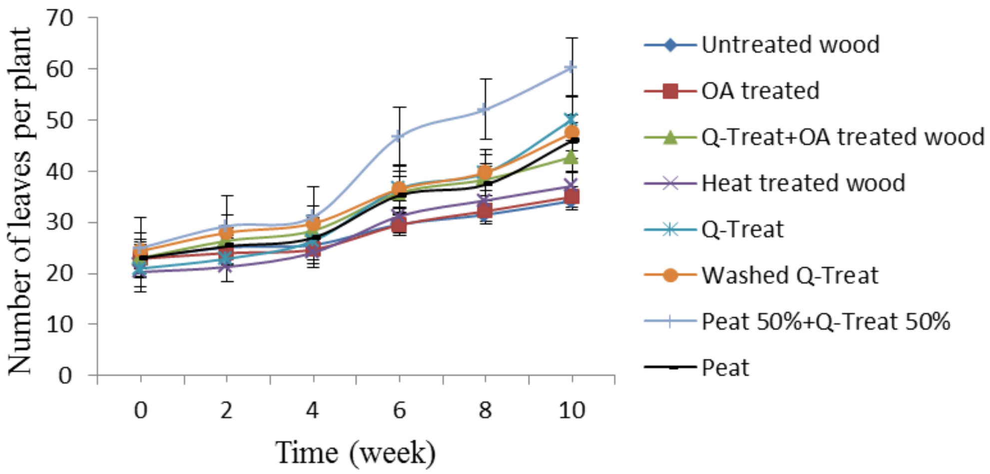


Figure 8. Leaf number of *Hosta* 'Golden Tiara' plants growing on eight different substrates. Vertical lines represent ±SD (n = 9).

The height, width, canopy volume and root length of *Hosta* 'Golden Tiara' plants differed among the substrates; however, differences in petiole length were non-significant (Table 6). Generally, height, width and canopy volume of the plants were greater on P50Q50 and lower on U. However, root lengths were higher on peat, P50Q50, washed Q, Q and H than on U, OA and Q+OA wood substrates.

Table 6. Petiole length (cm) of the third youngest leaf, width (cm), height (cm), canopy volume (cm^3) and root lengths (cm) of *Hosta* 'Golden Tiara' plants grown on eight different substrates. Means followed by different letters were significantly different at *P* ≤ 0.05 in Tukey's test (n = 9).

Substrate	Petiole length (cm)	Height of the canopy (cm)	Width of the canopy (cm)	Canopy volume (cm^3)	Root length (cm)
Untreated wood	14.1	17.5 c	31.7 b	1109 cd	9.6 c
OA treated wood	12.8	19.7 b	30.6 b	741 d	10.9 b
Q-Treat+OA treated wood	11.0	20.8 b	31.7 b	1095 cd	10.4 b
Heat treated wood	16.3	19.1 b	31.6 b	1629 b	11.1 a
Q-Treat	12.6	22.2 ab	34.6 ab	1457 bc	12.1 a
Washed Q-Treat	11.4	22.4 ab	35.3 ab	1458 bc	12.0 a
Peat 50%+Q-Treat 50%	16.1	23.4 a	38.0 a	2372 a	12.7 a
Peat	15.8	21.3 b	33.2 ab	1666 b	11.9 a
P	n.s.	<0.001	0.001	<0.001	0.002

The leaf dry weight, root dry weight, inflorescence dry weight, total dry weight, and leaf area were different in *Hosta* 'Golden Tiara' on eight different substrates (Table 7). Generally, P50Q50 was high and U was low in all of the parameters presented in table 7. A larger leaf area was found on P50Q50 than on U.

Table 7. Dry weight (DW) of different parts (leaves, roots, inflorescences, total) and leaf area of *Hosta* plants grown on eight different substrates harvested 90 days after transplanting. Means (n=9) followed by different letters were significantly different at $P \leq 0.05$ in Tukey´s test.

Substrate	DW of leaves (g)	DW of root (g)	DW of inflo-rescence (g)	Total DW (g)	Leaf area (cm^2)
Untreated wood	27.4 b	41.0 b	14.1 b	82.5 b	601 b
OA treated wood	31.0 ab	52.2 ab	15.1 ab	98.4 b	1352 ab
Q-Treat+OA treated wood	29.0 b	50.9 ab	15.5 ab	95.5 b	1340 ab
Heat treated wood	31.9 ab	46.2 b	15.3 ab	93.5 b	1506 ab
Q-Treat	30.0 ab	47.6 b	14.4 b	92.0 b	1539 ab
Washed Q-Treat	26.1 b	57.6 ab	17.1 ab	101.0 ab	1460 ab
Peat 50%+Q-Treat 50%	37.7 a	71.1 a	18.6 a	127.5 a	1957 a
Peat	29.3 b	58.1 ab	14.5 ab	102.0 ab	1686 a
P	0.003	0.003	0.014	<0.001	0.001

On visual observation, diseased, yellowish leaves, and deep-reddish corner leaves were found on U, OA, and H (Figure 9). Green and almost disease-free leaves were found on Q, P50Q50 and peat. Good canopy was visible in Q50P50. Roots on peat appeared compact and short in length. U, OA, washed Q-Treat, and Q+OA produced roots which were smaller in size compared to the others. Long and heavy roots were found on P50Q50.

Substrate	Leaves	Plant	Roots
Untreated wood			
Organic acid treated wood			
Heat treated wood			
Washed Q-Treat			
Q-Treat+Organic acid treated wood			
Q-Treat			
Peat 50%+Q-Treat 50%			
Peat			

Figure 9. The *Hosta* 'Golden Tiara' plants grown on eight different substrates. The photos were taken after washing the roots (harvested on 12 September 2013).

5.3.3 Generative growth

The number of inflorescences of *Hosta* 'Golden Tiara' plants on Q was higher than on other substrates at weeks 2 to 10, but no differences were found in the last week (week 12) (Figure 10). The substrate had an effect on both the number of inflorescences (P = 0.05) and the total length of inflorescences. The total length of inflorescences per plant was higher on Q (235.6 cm) than on U (159.8 cm) and OA (170 cm) (Figure 11). No significant differences were found among the other substrates.

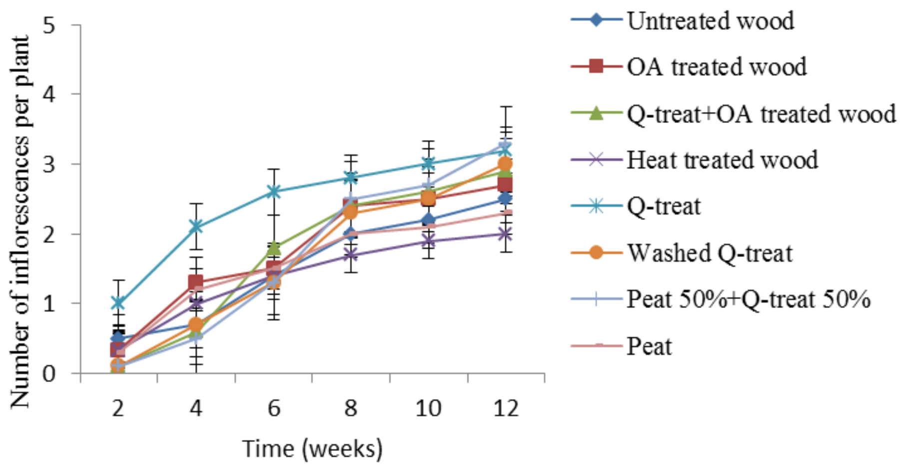


Figure 10. Inflorescence number on *Hosta* 'Golden Tiara' plants growing on the eight different substrates. Vertical lines represent ±SD (n = 9).

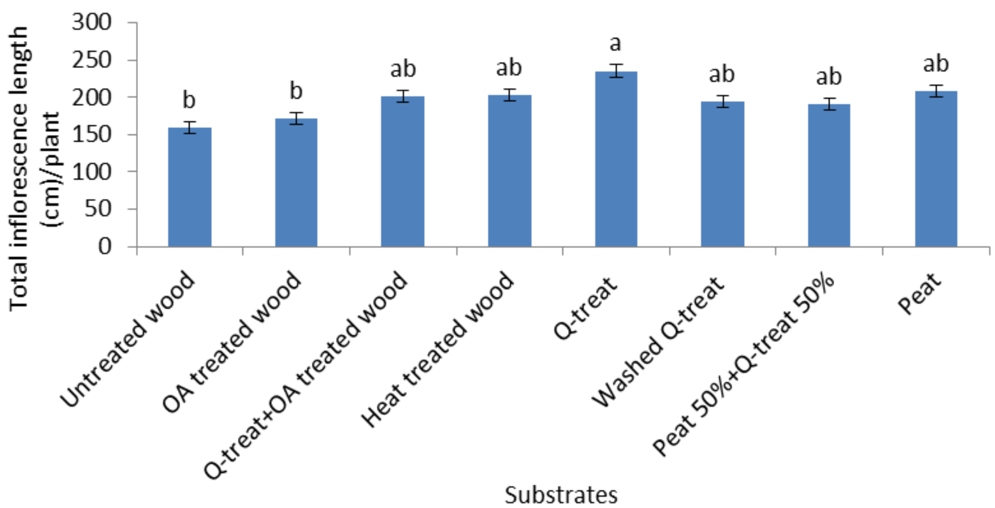


Figure 11. Total length of all inflorescences of *Hosta* 'Golden Tiara' plants grown on eight different substrates for 12 weeks. Vertical bars represent ±SD (n = 9).

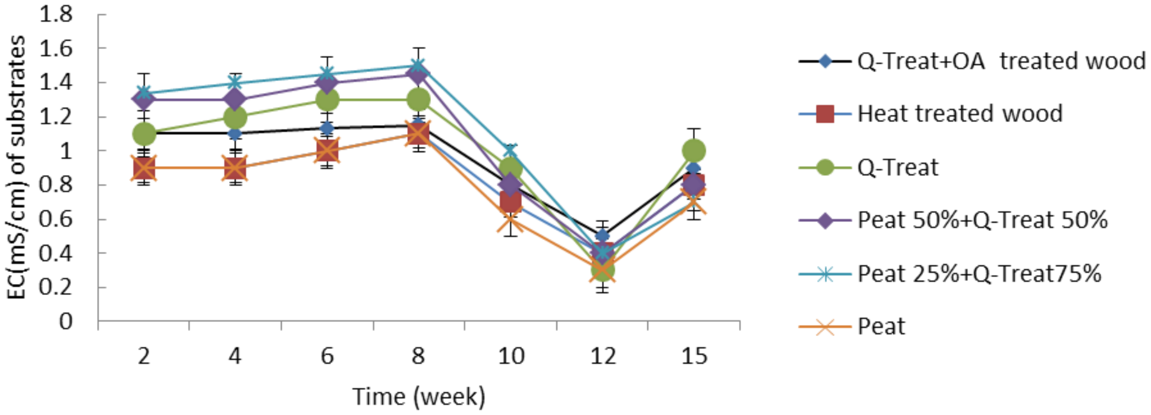
5.4 Strawberry production

5.4.1 pH, EC and water content of growing media

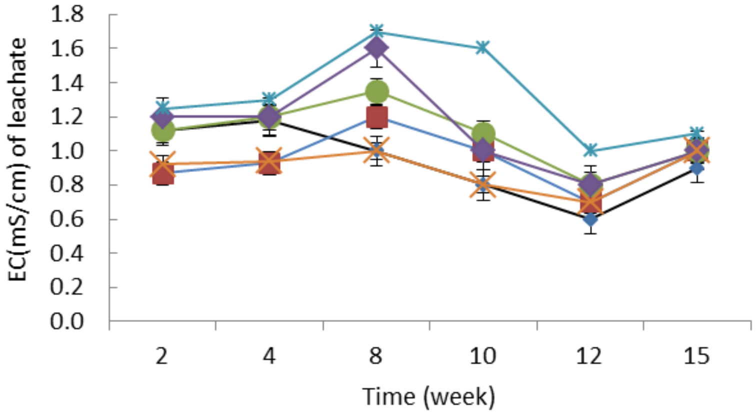
Generally, no significant differences were found in EC values between the substrates throughout the experimental period. The EC of the growing media was initially 1.0–1.4 mS/cm and declined rapidly after 8 weeks; however, in the last phase of the experimental period it increased slightly for all substrates (Figure 12 a). The trend of the EC of the leaching water was similar to that for the substrates. The range of EC values in the leaching water was 0.8–1.6 (Figure 12 b). At the end of the experiment a slight upward trend was found in the EC value of both leaching water and substrates.

The water content differed among the different substrates at the beginning of the experiment (weeks 2 to 4), where that of peat and P50Q50 was high and that of Q+OA was low (Figure 12c). During the first two weeks it decreased to a very low level and then each two weeks it decreased and subsequently increased. After six weeks, both peat and P50Q75 were high and H low in water content. However, during the last phase (from week 10 to week 15) of the experiment, there were no significant differences found among the substrates.

a)



b)



c)

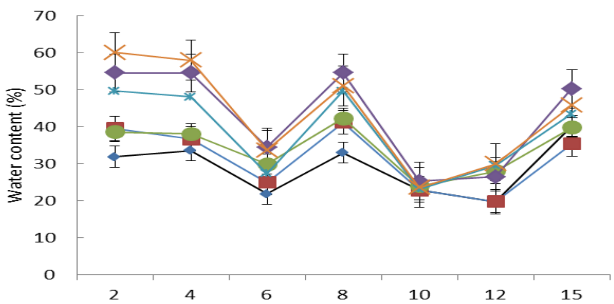


Figure 12. Electrical conductivity, (EC) (mS/cm), of substrates (Figure12a), EC (mS/cm) of leaching water (Figure 12b), and water content of the substrates (Figure 12c), measured in different growing media. Vertical lines represent ±SD (n = 12).

The pH of all wood substrates and peat was between 6.4 and 8.3 throughout the experiment (Table 8). At the beginning, the pH of all the growing media remained between 6.1 and 7.1, and it was significantly different in different substrates. In the second week, peat mixtures had a higher pH than H and peat. Moreover, the pH value increased slightly (from 7.0–8.3) at the end of the experiment, but the difference was no longer statistically significant.

Table 8. pH of leaching water measured from different growing media every two weeks after planting the strawberry plants. Means followed by different letters were significantly different at $P \leq 0.05$ in Tukey's test (n=12).

Substrate	Time (weeks)						
	2	4	6	8	10	12	15
Q-Treat +OA treated wood	6.8 ab	6.7 c	6.9 b	7.1	6.3 b	7.3	8.1
Heat treated wood	6.4 bc	6.5 c	6.7 c	7.0	6.4 b	7.3	7.6
Q-Treat	6.9 ab	7.1 ab	7.3 a	7.6	6.1 c	7.0	7.8
Peat 50%+Q-Treat 50%	7.1 a	7.3 a	7.4 a	7.3	6.8 b	7.1	7.5
Peat 25%+Q-Treat75%	7.0 a	7.1 b	7.3 a	7.8	7.1 a	7.0	8.3
Peat	6.1 c	6.5 c	6.7 c	7.8	7.2 a	7.0	7.5
P	<0.001	0.001	<0.001	n.s.	<0.001	n.s.	n.s.

5.4.2 Vegetative growth of strawberry plants

The number of leaves of the strawberry plants increased gradually throughout the experiment regardless of substrate (Figure 13). There were on average four leaves per plant two weeks after transplanting , and the number was almost the same on all growing media. The effect of substrates on the number of leaves per plant was not significant.

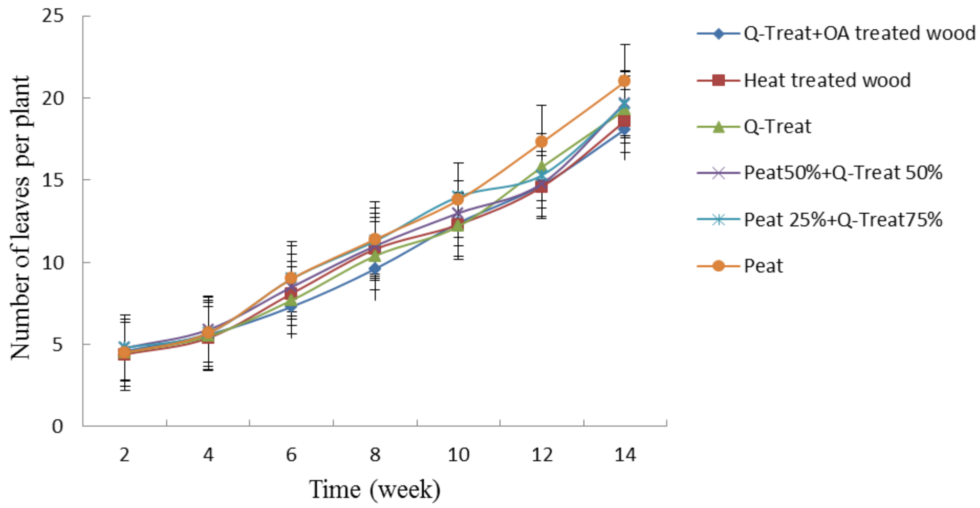


Figure 13. Leaf number in strawberry plants grown on six different substrates. Vertical lines represent ±SD (n = 32).

Petiole length differed significantly between the treatments at weeks 2, 4, 6, and 10 (Table 9). No difference in petiole length between the treatments was observed towards the end of the experiment (weeks 8, 12 and 15). Petiole length increased slowly from the beginning towards the end of the experiment.

Table 9. The length of the petiole (cm) of the third youngest leaf in strawberry plants grown on six different substrates. Means followed by different letters were significantly different at $P \leq 0.05$ in Tukey´s test (n = 32).

Substrate	Observation time (week)						
	2	4	6	8	10	12	15
Q-Treat+OA treated wood	8.9 bc	14.0 b	17.8 bc	19.2	20.0 ab	20.5	21.4
Heat treated wood	7.3 d	12.7 c	17.3 cd	19.1	20.2 ab	20.4	22.0
Q-Treat	10.2 a	14.2 b	16.9 d	19.3	19.5 b	20.0	21.7
Peat50%+Q-Treat 50%	9.5 ab	16.0 a	18.7 a	19.5	21.5 a	21.2	21.6
Peat 25%+Q-Treat75%	9.9 a	15.7 a	17.0 b	20.0	20.2 ab	20.5	23.2
Peat	8.6 c	16.1 a	18.2 b	20.1	19.7 b	20.1	22.0
P	<0.001	<0.001	<0.001	n.s.	0.009	n.s.	n.s.

Runner production started after four weeks in all treatments (Table 10). However, only a few runners were formed within the first two months of the growing period, with a rapid increase in the last two months. Differences in runner production between treatments were observed until the fifth and 10th week of the growing period. The lowest total number of runners was produced on Q+OA and the highest was found on peat and P50Q50. The highest dry weight of runners (g/plant) was found on peat substrate.

Table 10. Number of runners per plant and dry weight (DW) of runners (g/plant) in strawberry plants on six different substrates. Means followed by different letters were significantly different at $P \leq 0.05$ in Tukey's test (n= 32).

Substrate	Time (weeks)						
	5	10	15	Total	5	10	15
	Number of runners/plant				DW of runners (g/plant)		
Q-Treat+OA treated wood	1.1 bc	3.5 b	3.1	7.6 c	3.7 b	22.4 c	7.1 b
Heat treated wood	1.0 bc	4.6 b	2.7	8.0 b	3.7 b	18 c	7.1 b
Q-Treat	0.6 c	3.7 b	4.2	8.2 b	2.0 c	23.5 bc	6.0 b
Peat 50%+Q-Treat 50%	1.3 b	6.7 a	4.7	12.3 a	3.4 bc	28.3 b	7.3 b
Peat 25%+Q-Treat 75%	1.3 bc	4.8 b	3.3	9.0 b	3.0 bc	22.1 c	6.4 b
Peat	2.2 a	6.8 a	4.5	13.4 a	6.0 a	37.6 a	11.5 a
P	0.001	0.001	n.s.	0.002	0.001	0.001	0.001

By visual observation, well-developed primary roots of strawberry plants were found on almost all of the growing media (Figure 14). However, thin and short secondary roots were found on OA, H and Q. Large number of secondary roots were found on Q75P25 and Q50P50 and peat. But well developed and strong primary and secondary roots were found on the substrates of P50Q50 and P25Q75.

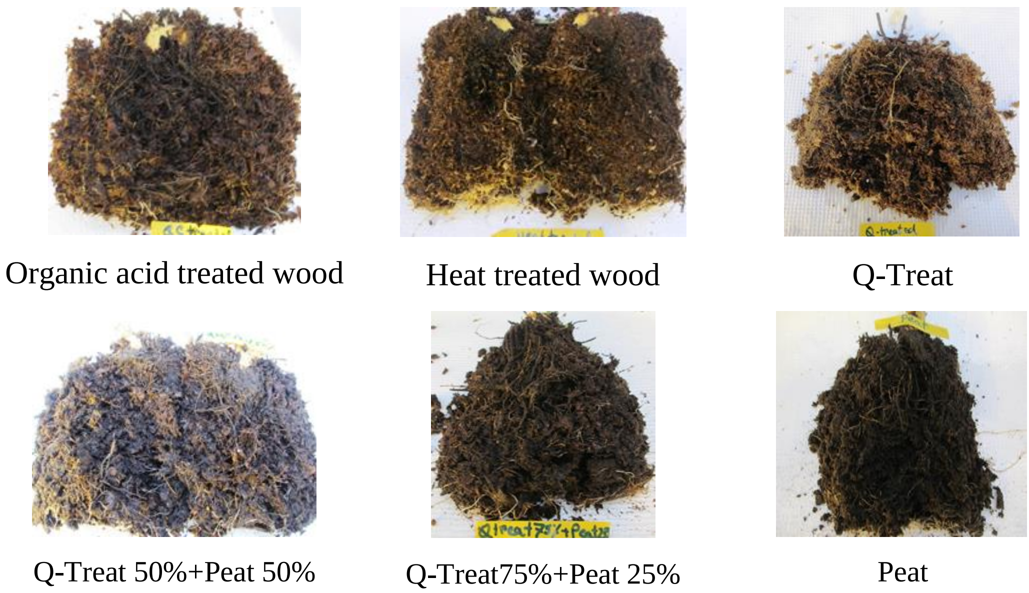


Figure 14. Root system of strawberry grown on six different substrates. The photos were taken after cutting root system longitudinally.

Analysis of the dry weights (DW) of leaves, roots, and runners, and the total DW of plants indicated that the total weight of the strawberry plants differed among the substrates (Table 11). A higher level of leaf DW was found on peat and peat-containing media than on the wood media. Root DW on peat was significantly higher than on H. The highest level of runner DW was found on peat and P50Q50. Total DW among all of the substrates was highest on peat. Leaf area showed a similar result to that of total DW, being highest on peat and P50Q50, with the lowest on Q+OA.

Table 11. Dry weight (DW) of different vegetative parts of strawberry plants grown on six different substrates. Means (n=32) followed by different letters were significantly different at $P \leq 0.05$ in Tukey's test. Leaf area was measured from two randomly selected plants per treatment (n=8).

Substrate	DW of leaves (g/plant)	DW of root (g/plant)	DW of runners (g/plant)	Total DW (g/plant)	Leaf area (cm^2/plant)
Q-Treat+OA treated wood	28.6 b	12.1 ab	34.0 bc	74.8 c	2591 d
Heat treated wood	32.3 b	11.5 b	28.0 c	74.0 c	2970 c
Q-Treat	31.8 b	13.8 ab	31.6 c	78.5 c	3307 b
Peat 50%+Q-Treat 50%	36.4 a	14.9 ab	39.0 a	90.3 b	4121 a
Peat 25%+Q-Treat 75%	33.1 ab	14.7 ab	31.5 c	79.0 c	3315 b
Peat	36.6 a	15.5 a	55.2 a	107.3 a	3993 a
P	0.002	0.019	0.001	<0.001	0.001

The plants on all substrates contained almost the same amount of nutrients, except Zn and Mg (Table 12). The plants grown on peat and peat mixtures had a higher level of Mg than those grown on wood growing media without peat. In the case of micronutrients, significant differences in Zn were found among the substrates, which was higher in plants grown on P25Q75 than on Q+OA and Q.

Table 12. Effect of six different substrates on the contents of nutrients in strawberry leaves. Means followed by different letters were significantly different at $P \leq 0.05$ at Tukey's test (n= 2).

Substrate	Macronutrients (g/kg)					Micronutrients (mg/kg)				
	N	P	K	Ca	Mg	S	B	Fe	Mn	Zn
Q-Treat+OA treated wood	22.6	4.4	26	15	3.6 b	1.4	52.5	52.5	270	21.5 b
Heat treated wood	21.5	4.3	26	22	3.6 b	1.5	62.0	50.5	180	27.5 ab
Q-Treat	21.9	4.9	26	16	3.4 b	1.3	54.0	57.5	230	22.0 b
Peat 50% + Q-Treat 50%	22.0	4.8	24	17	3.9 ab	1.3	55.5	49.5	118	26.0 ab
Peat 25% + Q-Treat 75%	22.3	5.0	26.5	19.5	4.2 ab	1.4	55.0	60.5	103	30.0 a
Peat	21.5	4.2	23	18	4.5 a	1.4	50.0	74.0	52	27.5 ab
P	n.s.	n.s.	n.s.	n.s.	0.009	n.s.	n.s.	n.s.	n.s.	0.018

5.4.3 Fruit yield

The first flowers opened at days 21 to 29 (7 October to 15 October) after transplanting (Figure 15). The first flower opened one day earlier on Q+OA, Q, and P25Q75 than on P50Q50, H and peat substrates.

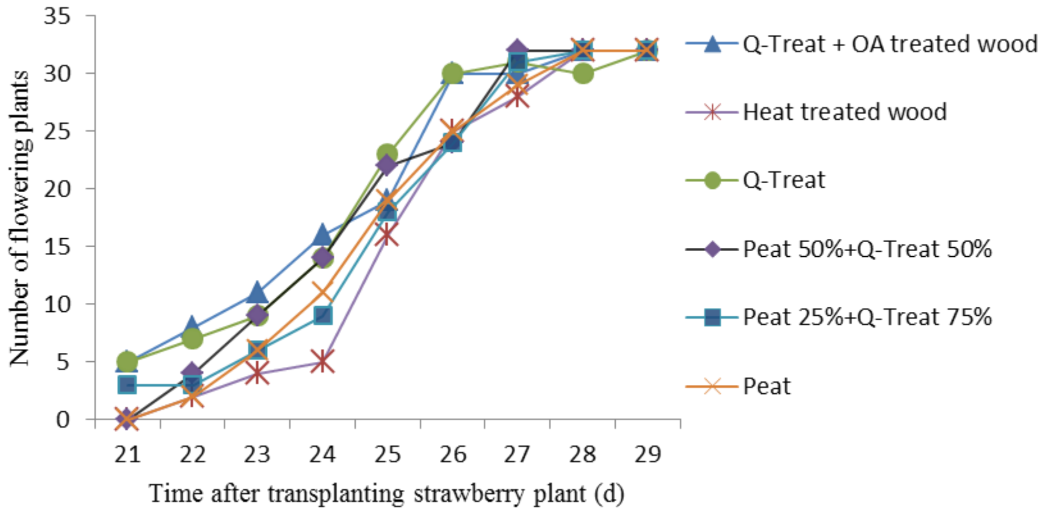


Figure 15. Number of flowering plants out of a total of 32 strawberry plants, on six different substrates.

Different growing media exhibited significant differences in total fruit number and total marketable yield (g) per plant, but no significant differences were found in average berry weight (Table 13). The highest number of berries per plant was recorded in plants grown on P25Q75, and the lowest in those on Q+OA and H substrates (Table 13, Figure 16). Berry yield was highest on the substrates of P25Q75 and peat, and lowest on Q+OA substrates. The difference in average berry weight was non-significant among the substrates.

Table 13. Number of fruits, fruit yield (g) and average fruit weight (g) per plant of strawberry grown in different substrates. Means followed by different letters were significantly different at $P \leq 0.05$ in Tukey's test (n = 32).

Substrate	Number of fruits/plant	Yield (g/plant)	Average fruit weight (g)
Q-Treat+OA treated wood	13.9 c	166.2 d	12.7
Heat treated wood	15.1 c	185.6 c	12.4
Q-Treat	17.5 b	210.8 b	12.2
Peat 50%+Q-Treat 50%	16.9 b	211.8 b	12.5
Peat 25%+Q-Treat 75%	18.9 a	224.0 a	12.0
Peat	17.1 b	226.6 a	13.1
P	0.001	0.001	n.s.

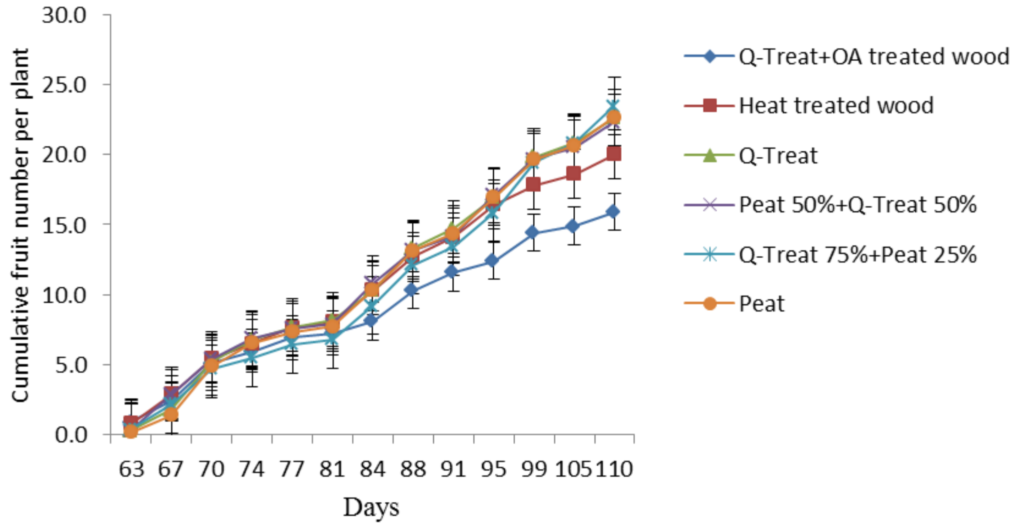


Figure 16. Cumulative number of harvested fruits when strawberry plants were grown on six different substrates. Vertical lines represent ± SD (n = 32).

The weekly yield from strawberry plants on different substrates showed an upward trend at the beginning of the harvest season and a downward one at the end (Figure 17). After 77 days, the yield of berries decreased quite rapidly and then a slight upward trend was observed. On peat, the downward trend found between day 77 and day 91was very sharp (100g to 20g). All of the substrates showed very similar types of upward and downward trend in berry yield.

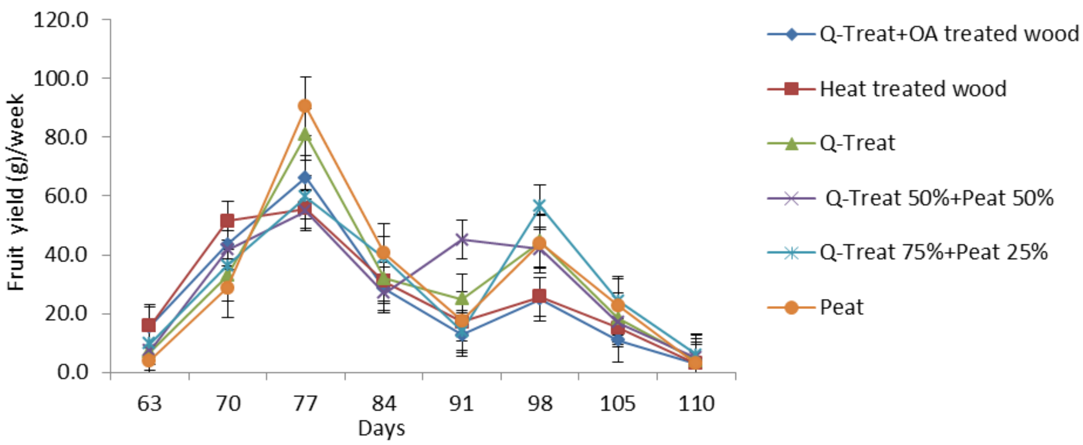


Figure 17. Weekly fruit yield (g) of strawberry plants grown on six different substrates. Vertical lines represent ± SD (n = 32).

Fruit size differed at different times during the harvest, but no differences were found among the substrates (Figure 18). The fruit size dropped steadily from 17.3–24.8g to 4.3–6.6g between day 63 and day 77. It remained constant at about 4.3–6.6g from day 77 until day 91. From this time onwards, it climbed steadily (from 4.3–6.6 to 8–15g) and at the last measurement (day 112) it had slowly declined. Fruits were larger at the beginning than during the middle and at the end of the experiment. Small fruits were found in the middle stages but during the last phases their size increased again, except at the last measurement.

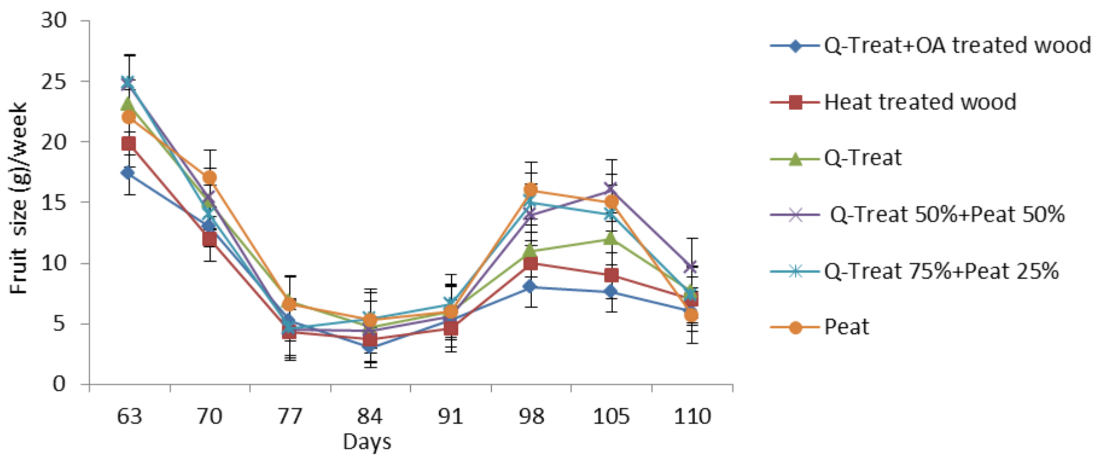


Figure 18. Weekly average fruit size (g) of strawberry plants grown on six different substrates. Vertical lines represent ± SD (n = 32).

5.4.4 Yield quality

At the first measurement time, significant differences in the fruit dry matter content did not appear between the substrates (Table 14). Moreover, in second measurement time, no differences were observed in fruit dry matter content among the substrates.

Table 14. Fruit dry matter content (%) of strawberry grown in different substrates. Means followed by different letters were significantly different at $P \leq 0.05$ in Tukey's test (n =12).

Substrate	Fruit dry matter content (%)	
	22.11.13	22.12.13
Q-Treat+OA treated wood	17.5	15.8
Heat treated wood	17.9	19.3
Q-Treat	18.1	16.3
Peat 50%+Q-Treat 50%	19.0	17.4
Peat 25%+Q-Treat 75%	16.7	18.1
Peat	17.5	19.2
P	n.s.	n.s.

Acid content (%) and sugar-to-acid ratio of strawberry fruits were not significantly different between the substrates at the beginning, middle or end of the harvest (Table 15). Sugar content ($^{\circ}$Brix) differed between substrates at the time of the first observation but did not differ at the mid- or last-observation times. A higher sugar content was found on H than on P25Q75.

Table 15. Contents of soluble solids, per centage of titratable acids, and sugar to acid ratio in strawberry fruits grown on six different substrates. Means followed by different letters were significantly different at $P \leq 0.05$ in Tukey's test (n=16).

Substrates	°Brix			Acid content (%)		Sugar:Acid	
	25.11.13	05.12.13	23.12.13	05.12.13	23.12.13	05.12.13	23.12.13
Q-Treat+OA treated wood	9.2 ab	10.0	8.7	1.0	0.97	10.0	9.0
Heat treated wood	9.6 a	9.5	8.6	1.0	0.94	9.5	9.2
Q-Treat	9.1 ab	9.0	9.1	0.99	0.91	9.0	9.9
Peat 50%+Q-Treat 50%	9.4 ab	9.1	8.6	0.97	0.94	9.3	9.2
Peat 25%+Q-Treat 75%	8.3 b	8.5	8.7	0.99	0.95	8.5	9.1
Peat	9.0 ab	9.0	8.6	0.98	0.94	9.1	9.2
P	0.048	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

6 DISCUSSION

6.1 Characteristics of growing media

Analysis of growing media with different parameters such as EC, pH, water holding capacity, N immobilization and phytotoxicity are very important to the selection process of growing media, quality control, recommendation of growing media and advice regarding fertilization (Gutierrez et al. 2007, Raviv & Lieth 2008, Gabriel et al. 2009, Neocleous et al. 2013). Therefore, to establish a relationship between growing media and plant performance, the following experiments were conducted:

6.1.1 Phytotoxicity

Ortega et al. (1996) conducted an experiment regarding the behaviour of different horticultural species growing on forestry wastes (cork, oak barks) and noted that tomato and lettuce were sensitive species which could be used in growth tests. Lettuce and tomato were therefore chosen for this phytotoxicity bioassay, because both species are highly sensitive to phytotoxicity (Zucconi et al. 1985, Ortega et al. 1996, Veronneru et al. 1997, Rathinasabapathi et al. 2005). On Q-Treat, germination percentages for both lettuce and tomato were found to be significantly higher on washed substrate as compared to the unwashed substrates. However, no difference was observed in the germination response of either species on the other substrates when phenolic content was washed out using a hot-water treatment. Germination percentages for both species on all the substrates were found to be lower than 50%. Bustamante et al. (2008) conducted research on peat and compost as growing media in relation to seed germination in lettuce, and observed 100% seed germination and 0.136g/seedling dry weight in peat, and 100% seed germination, 0.089g/seedling dry weight in compost. Our findings differed from the above regarding seed germination and dry weight yield, a variation which could be due to lack of nutrients in the substrates in our experiment, as they were unfertilized. Another reason for the huge variation of germination percentages on different substrates may have been the use of a smaller number of replicates (10 replicates for each treatment).

The dry weight of seedlings was found to be high for all wood growing-media except OA (both washed and unwashed), washed Q+OA and peat. Washing of Q+OA and OA substrates inhibited the growth of tomato plants; this may have happened due to the drying out of the seedlings two weeks after seed sowing. Previously, Ortega et al. (1996) had found that the washing procedure helped to reduce up to 80% to 90% of phenolic contents after the hot water treatment of bark substrates, whereas in our experiment, the washed substrates generally did not show a positive response in the growth of either species. In our experiment, neither crop grew well on all the substrates, which might have been due to the high content of water and the lack of nutrients in the substrates. In the phytotoxicity assay experiment, all of the growing media were unfertilized, and therefore unfertilized peat was chosen for this assay.

Raviv and Lieth (2008) observed that a favourable pH for germination of horticultural crop species is in the range of 6.5–7.5. However, in our experiment, the pH of the peat, OA, and H substrates was lower than this, i.e. 4.2, 4.6 and 3.0 for peat, OA and H, respectively. This low pH could be a reason for the lower germination. The highest EC was found in Q and Q+OA, and the lowest in U, washed U, H, washed OA and washed

Q+OA. Though there were some significant differences in EC values between different substrates, the ranges of the values were very low (0.10–0.45 mS/cm). This finding agrees with the previous studies conducted by Raviv and Lieth (2008), where EC value was found to be very low in both wood fibres and unfertilized peat. However, another study has found that the low EC (1.25 mS/cm) of soilless growing media provides reasonable growth and yields from tomato plants (Mokktari et al. 2013). A phytotoxicity was done without fertilization of the growing media, which means that the EC value indicates the nutrient status of the growing media. However, in our experiment, washing reduced the EC in Q and Q+OA. Both of these substrates contain Q-Treat, which is chemically modified. From this result, we would say that Q-Treat is suitable for plant production without washing.

Generally, water content was found to be high in peat, Q+OA, OA and H. Substrate water availability and seed water content can affect the first germination stage. Masetto et al. (2013) found higher germination and seedling growth with a low water content (11.3–4.6%), and this may be the reason for the low germination (below 50%) in this experiment, in which there was a high water content in the substrates. Klamkowski et al. (2006) stated that a favourable water content of any growing medium is an important factor for the growth and development of the plant. H, OA and peat have a high water content, because they have very low particle size, which means that they can hold water for a long time. These findings support the statement of Raviv (2005), who also found that low-particle-sized substrates can hold water for a long time. Particle size was not measured in our experiment, but rather was observed visually. Due to the high radiation, substrates dried out quickly, but in the case of a rainy or cloudy day, they all remained wet. Because the same amount of water was given to all pots, peat and other media with small particle size were often very wet, and therefore the seedlings' growth status was not satisfactory in peat. In fact, a growing medium needs a different level of irrigation depending on certain physical properties of the substrate, such as particle size and bulk density, as well as climatic conditions (e.g. radiation, day length). It may be possible to achieve a better performance if watering is done three to four times a day at regular intervals, providing small amounts of water each time. Another reason for the poor growth in our plants may have been a lack of nutrients, because a high level of watering leaches out the nutrients of the growing media. Two weeks after germination, all of the plants became yellowish and dried out due to lack of nutrients. In the phytotoxicity, tomato and lettuce germinated well on all growing media. It can be concluded that all wood-shavings can be used for horticultural plant production purposes.

6.1.2 Water holding capacity

The water holding capacity (WHC) of a substrate is the amount of water that it can hold. WHC is a major factor for growth and yield of horticultural plant species (Klamkowski et al. 2006), and depends mainly on the size of the medium's particles. If the WHC falls below 50%, plants can suffer from drought. In contrast, when the WHC is high, the plants begin to suffer from lack of oxygen. Usually substrates that have fine particles can hold more water than coarse substrates. WHC is an essential characteristic of growing media for screening, quality control and recommendations for new media (Klamkowski et al. 2006, Raviv & Lieth 2008).

In our experiment Q, OA, and P50Q50 had a higher WHC than U, H, Q+OA, and washed Q, whereas peat did not show any significant differences between lower and higher values of WHC. Q-Treat has large particle size, and is treated with sodium silicate, which is why its water absorbance capacity is high (Stora Enso Wood Products Oy Ltd. 2014). In the current experiment, the WHC of substrates lay between 298% and 481% of dry weight. Previous research has found 600–1000 ml/l to be the optimum range WHC for growing media (Abad et al. 1989). For peat, specifically, the water content was found to be 614 ml/l (Sambo et al. 2008). In the current experiment, WHC was not measured by volume, but was measured from the dry weight of substrates. WHC depends on the species of peat; for example, the WHC of sphagnum peat moss is 1500–3000%, and in decomposed peat it is150–500% (CSPMA 2014). The amount of WHC in our experiment was lower than the optimum ranges for growing media which have been reported in previous research. The reasons for this may be due to the physical characteristics of the substrates. Research has shown that wood fibres and sawdust have high percentages of total porosity (91.4–93.2%), and wood-based media generally hold a lower content of available water (14.6–27.3%) than peat (Arenas et al. 2002, Raviv & Lieth 2008).

The WHC of peat was not found to be any different from wood substrates in our experiment. However, according to other research, the WHC of peat is greater than wood fibres and coconut coir (Abad et al. 2005, Lopez-Galarza et al. 2010, Raviv et al. 2005). This inconsistency of results with the previous studies could be due to the fact that sphagnum peat was used in the previous research, whereas our study used wood substrates which were treated (either physically or chemically).

6.1.3 Inorganic nitrogen

Nitrogen is an essential macronutrient of plants. It is one of the components of chlorophyll; chlorophyll is also an important compound of photosynthesis. Nitrogen deficiency in plants can reduce early plant growth and yield. Brown and Naeth (2014) found that the nitrogen content of plants increased with an increase in the quantity of compost. The same study also found that the nitrate accumulation rate was a function of the rate of nitrogen application. In our experiment, a high C/N ratio was found in OA and a low ratio in peat and Q. The optimal range of C/N of substrates like peat, compost, and peat mixes is between 20:1 and 40:1 (Abad et al. 1989). In our experiment, the C/N ratio of peat was 60:1, which was higher than the findings of previous studies (Whalen & Sampedro 2010, Dumroese et al. 2011). Moreover, the C/N of wood fibres was lower (96:1–220:1) than some other research on pine sawdust (729:1), and that of oak residues was 200:1 (Whalen & Sampedro 2010). For example, unfertilized peat (40:1) has a lower C/N than fertilized peat (47:1) (Dumroese et al. 2011). It seems that the C/N of wood substrates is mostly high, and this indicates a low amount of N present in the substrates. In our study, the C/N of wood substrates was higher than the optimum ranges, which agrees with the results of earlier studies.

Generally, the mineral inorganic N% of all the substrates remained between 0.000 and 0.002. The peat or peat-mixture substrates were low in N at maximum incubation time. Therefore peat did not show lower values than all of the wood substrates, but it was lower than some of them. This result partially supports those of some other studies (Prasad 1997, Brown & Naeth 2014), where N immobilization of wood fibre was also very high (0.15%). The reason for N immobilization of wood fibres is the microbial activity of the growing media (Prasad 1997). Microorganisms consume N during composting of organic materials. N was not immobilized in Q and Q+OA because these materials are treated against biodegradation, which is beneficial, since N is available to plants. Some studies have suggested that N immobilization of woody substrates would be better if the substrates were composted before planting (Handreck et al. 2002, Atland 2010). Gruda et al. (2009) found that 0.04% of water-soluble N was required for soilless substrates. In our study, all of the substrates had lower percentages, and therefore N had to be provided through fertigation.

A higher C/N enhances N immobilization. So wood-shavings could be used as a growing medium by adding additional N. However, the timing of N application is a factor affecting plant growth and development. Additional N fertilization and composting of substrates affects the growth and flowering of ornamental plants (Handreck & Black 2002).

6.1.4 Substrate conditions during cultivation of *Hosta* and strawberries

The pH, EC, and water content are the main parameters of any substrate for determining nutrient availability (Latigui et al. 2011). The pH of some substrates (Q 6.8, Q+OA 6.5, washed Q 6.4, and peat 6.0) in our experiment are similar to the findings of Raviv and Lieth (2008), where the pH levels of sawdust and peat varied from 6.3 to 7.7, and 3.5 to 4.1 respectively. Altland (2010) observed that the pH of pine bark and willow chips varied from 4.2–5.2 and 5.1–6.3 respectively. However, the pH of our wood substrates was higher than in the above study. On the contrary, another study found pH 5.2–5.7 and EC 0.27–0.62 in pine tree substrates at 3.5 kg/m^3 fertilizer rates (Jackson et al. 2008). Previous research has suggested that soilless media like unamended peat and pine bark had a low pH, and for these substrates $CaCo_3$ needed to be added to raise the pH according to the crop requirement (Jones et al. 1991, Acuna-Maldonado et al. 2008, Raviv & Lieth 2008). We measured the pH of growing substrates before planting crops, and some media (i.e. unfertilized peat, U, H, and OA) had a low pH, so $CaCo_3$ was added to raise it to an optimal level before planting *Hosta* ‘Golden Tiara’ and strawberries. The ideal pH range for *Hosta* is 6.5–7.5 (Heinke & Martin 2001). The pH of the substrates for *Hosta* ‘Golden Tiara’ cultivation was between 6 and 7 throughout the experimental period, which is very close to this ideal. There were no differences found between peat and wood substrates.

For strawberry production, the pH range of leachate was 6.1–8.1 throughout the cropping period. According to Noguera et al. (2000), and Caso et al. (2009), the optimum pH of growing media for strawberry production is from 5.3 to 6.3. During the last phase of our experiment, the pH of all of the growing media was higher than the recommendations. All of the substrates sometimes achieved a high pH at different measurement times. Therefore, both peat and wood substrates had a pH a little higher than was ideal during strawberry production.

The EC of the growing media is usually used as an indicator of available nutrient status, and it is an indicator of the soluble-salt concentration of the growing medium (Smider & Singh 2014). During *Hosta* 'Golden Tiara' cultivation, all the substrates and leachates had low EC values (0.1–0.3) at the very beginning but this increased (up to 0.65–1.89) in the last phase of the experiment, with Q+OA and Q higher than peat, P50Q50, H, OA and U substrates. Generally, the EC of ornamental plants in soilless culture are observed to be between 0.13 and 0.91 (Witcher et al. 2014). This study closely supports our observations. Cabrera et al. (2012) recommend that all the EC values of substrates for different *Hosta* species be between 1.3 and 4 dS/m. In our experiment, the EC values of Q and Q+OA for the last two weeks were found to be similar to other wood substrates (Cabrera et al. 2012). Moreover, the very low EC value recorded for the first few weeks could be due to the use of slow-release fertilizer for *Hosta* production. Similar results were found in similar types of work conducted by Witcher et al. (2014), who also stated that the reason for the low EC of the substrates in the first few weeks was due to the nutrient-release rate of the fertilizers. They also found that pH and EC were almost stable throughout ornamental plant production in all of the whole pine tree and peat substrates. Good growth was found at a low EC (2 dS/m) level in the ornamental plant *Lisianthus* 'Pure White' (Valdez-Aguilar et al. 2013). Beckmann-Cavalcante et al. (2013) stated that a higher EC (>3.5 mS/cm) inhibited the accumulation of nitrogen and of micronutrients, but stimulated the levels of P, K, Ca, Mg and S in the leaves of the ornamental plant chrysanthemum. Plant nutrients play an important role in the leaf-colour of ornamental plants.

No significant differences were found in EC between the substrates used for strawberry cultivation. However, the EC range of the substrates was 0.8–1.6 mS/cm for both leachate and substrates except at week 12 of the experiment. The optimum EC for strawberry production is between 0.75 and 3.5 mS/cm (Abad et al. 2001). Moreover, Andriolo et al (2009) found good yield and growth at an EC of 0.9–3.8 mS/cm. Similar results were observed by Caruso et al. (2004) in wild strawberries (*Fragaria vesca* L.), where good yield and growth were found at an EC of 1.3–2.2 mS/cm. However, Neocleous and Savvas (2013) reported that the higher EC (2.6–3.4 dS/m) caused a significant reduction in the plant growth and yield of strawberries. In our experiment, the EC value was lower than that and should not have been a cause of yield reduction in strawberries.

A high EC value (5.0 mS/cm) in soilless culture increases dehydration (Recamales et al. 2007, Gabriel et al. 2009) and consequently decreases the yield of horticultural plants (Raviv & Lieth 2008). Choi and Latigui (2011) stated that a lower EC affected the growth and yield of plants and a higher EC reduced the nutrient-uptake ability of the plant. Consequently, some nutrients should be added in case of a lower substrate-EC and water should be added to reduce the EC concentration of the substrates (Dalton et al. 2001). In our experiment, the EC values did not exceed the higher limit in either strawberry or *Hosta* ‘Golden Tiara’ production. This means that wood substrates are favourable for the production of both crops regarding EC values.

Water content is a physical parameter of a growing medium which characterizes the availability of water for plants in the growing medium (Lemnatec 2013). For both *Hosta* ‘Golden Tiara’ and strawberry production, the water content of peat and P50Q50 were higher than that of wood substrates except during the last two weeks. Peat-containing substrates appeared to have a higher water content than wood substrates. Similar results were found in previous studies, where wood substrates had a lower available water content than peat due to the high pore space of woody substrates (Raviv & Lieth 2008, Boyer et al. 2009, Jackson et al. 2008). Another reason may be bulk density, which is correlated with the water content of any substrate. Sahin et al. (2002) found that peat moss had a low bulk density (0.086g/cm^3) compared with wood substrates (325g/cm^3). Olle et al. (2012) showed a relationship between water content and fruit weight in soilless culture and stated that a low level of water reduced the fruit weight of strawberries in this type of culture.

In our experiment, substrates dried out quickly at different phases of growth and development during the experiment with strawberry and *Hosta* 'Golden Tiara' production. In the case of *Hosta*, the plants took up a higher volume of water from the substrates when they produced a higher canopy volume and larger-sized inflorescences, which is why every four weeks they required an increased level of irrigation. Moreover, the *Hosta* 'Golden Tiara' plants were cultivated outdoors in mid-June to mid-September. At that time, temperature and solar radiation was high, which may be the reason the substrates of the *Hosta* plants dried out quickly. In the case of strawberry production, though the plants were grown in controlled conditions in a greenhouse compartment, and required increased irrigation every two weeks when they were moving from one stage of development to another. For example, more irrigation was required during the harvesting stage than the flowering stage. It is therefore clear that when plants have more leaves and fruit they take up more water, which is why an increased irrigation rate is required at different growth stages.

6.2 *Hosta* 'Golden Tiara' production

In our study, we have determined the vegetative growth and generative growth within different parameters of *Hosta* 'Golden Tiara' and compared the prospects for future use of different wood substrates and peat. To our knowledge this is the first study of *Hosta* 'Golden Tiara' where plant production was carried out on the substrates of wood-shavings, peat and mixtures of wood with peat. In our study, different parameters of vegetative growth were found to be favourable on P50Q50. According to Altland (2010), the most vigorous growth and development (plant height, fresh and dry weight of shoots and roots) were found in the Benjamin tree (*Ficus benjamina* L.), using a combination of equal proportions of two soilless growing media. When comparisons were made among peat, sawdust, tree bark and compost substrates, a positive effect on qualitative and quantitative parameters in ornamental plant species was observed (D'Angelo et al. 1995, Zaller 2007). As seen from various growth parameters, similar observations were obtained in this experiment in *Hosta* 'Golden Tiara' production, where more vigorous growth was found on most of the parameters in plants grown on

P50Q50 than on wood or peat substrates. In relation to these studies, Gabriel et al. (2009) has suggested that a combination of peat and organic components, either wood or compost, could be an appropriate substitute for peat.

Total petiole length was 8.73–22.69 cm and leaf number per plant was 11.4–33.8 for different cultivars when the plants were grown on soil (Cabera et al. 2012). However, in our studies the petiole lengths were 11–15.6 cm and leaf numbers per plant were 28.3–56.7. The petiole length in our study was within the same ranges as the findings of the previous study; however, the leaf number was higher. Minor dissimilarities might be due to the fact that different cultivars of *Hosta* were used by the previous authors.

The observations of this study indicate that leaves and canopy develop gradually throughout the growing season, depending on the nutrition and irrigation water that the *Hosta* plants receive. Substrate characteristics are closely correlated with nutritional supply, which is an important factor for plant growth and development. In our experiment, root lengths were different in different substrates and were lower on U, OA and Q+OA substrates. Other studies found that root growth was not constant in the same plant species grown on different types of soil, but depended on soil texture and structure (Mostafiz et al. 2009). Witcher et al. (2014) also observed that root development depended on the physical properties of the substrates. Peat, peat mixes and some wood substrates produced long roots, though they had small particle size. Variable root length was found in plants on substrates with the same-sized particles. Therefore, we cannot make any conclusion regarding the effect of particle size on root length. In addition, there is a possibility that these differences are due to the physical or chemical properties of the substrates. Abouzari et al. (2012) conducted an experiment on soilless substrates and stated that different root lengths occurred due to the supply of nutrients to plants from substrates. The growth of some ornamental plants (*Polianthes tuberosa* L., *Hippeastrum vittatum,* and *Lawsonia inermis*) was closely correlated with the characteristics of their growing media (El-Naggar 2009).

6.3 Strawberry production

In the current investigation, vegetative growth was, in general, strong on peat and peat-containing substrates. This does not mean that peat gives higher yields, because vegetative growth in strawberries has a negative effect on fruit yield (Tagliavini et al. 2005, Neri et al. 2012). Moreover, higher vegetative growth is found when they are grown on peat; however, yield and quality were almost equal when grown on coir, plant fibre, peat and plant-fibre mixes, and peat substrates (Kuisma 2013). Generally, the amount of nutrient supplied by the substrates to the plants is assessed by the examination of the leaf tissues of the plants for the most important elements. Beckmann-Cavalcante et al. (2013) observed that the condition of the substrates had an effect on the accumulation of nutrients in the plants. Other research found that N was responsible for slightly increasing the yield quality of berries (Hochmuth et al. 1996, Miner et al. 1997) whereas Mg and Zn were responsible for increasing the yield of strawberries (Lieten 2006, Almaliotis et al. 2002). In our experiment, a similar level of nutrients (except Mg and Zn) was found in all of the substrates. Higher Mg and Zn were found in peat and peat-mixture substrates, although the differences were very small. Because the yield and yield quality were almost the same for all of the substrates, it can be concluded that the nutrient supply capacity of all the substrates was sufficient.

In our experiment, the first-flower-opening time was very similar among all of the substrates, and opening began within two days. In previous research, Ayesha et al. (2011) found delayed reproduction in more nutritive media and early reproduction in less nutritive media. Taking these findings of this previous study into account, it can be seen that the nutrient status of all of the substrates was almost the same in the current investigation.

In our experiment, the number of fruits was highest in plants grown on P25Q75 and the yield was highest on peat and P25Q75. Similar findings have been observed in previous research. Cantliffe et al. (2003) stated that no differences were found in berry yield and size when strawberries were grown on various types of soilless substrate. Kuisma (2013) indicated that no differences were found in yield quantity, with minor differences in yield quality, in strawberries grown on peat, coir, plant fibre and plan fibre/peat-mixture substrates. In our experiment, runner production was lower on P25Q75, which means that growers do not need to waste time removing runners during strawberry production. Taking into account yield, quality and low runner-production, it can be concluded that 75% peat could be replaced by Q-Treat.

Some inflorescences were broken during measurement of the vegetative growth (counting leaves and runners, measuring petiole length), and this may have caused some difference in berry yield between the substrates. During the middle two weeks of the harvest period, the berries were smaller than in the first and last two weeks. Although berry size usually decreases in the last phase, in our study it increased. This may have been a result of the continuous supply of irrigation (water and nutrients), which was increased every two weeks. Similar findings have been shown in previous research, where the nutrient supply was found to affect the yield of berries (Ayesha et al. 2011, Neri et al. 2012).

The dry-matter content, soluble solids, sugar/acid ratio and acid content were assayed to determine the quality of berries growing on different wood media and peat substrates. In our experiment, total soluble solids were 8.3–10 °Brix at different periods of the harvest and were not affected by the substrates. Previous studies have found total soluble solids and titratable acid to be 10.50 °Brix, ranging from 6.3 to 10.86 and 0.68g citric acid/100g respectively (De Souza et al. 2014). However, Recamalesin et al. (2007) found 7.3–10 °Brix in berries grown on peat and 7.3–9.6 °Brix on compost substrates. Therefore, our results were completely consistent with previous findings. For acid content in berries, all the substrates provided the same percentages.

The ratio of sugar content (°Brix) and acid is an indicator of good berry flavour (MacNaeidhe 2001). MacNaeidhe’s research showed that the range of sugar/acid of the best flavoured berry was 8–11. In our work, the range of sugar/acid was 8.5–10. This ratio indicates that the berries were the best-flavoured. There were no sugar/acid differences on any of the substrates, which means that all of them produced berries with a good flavour. In our study, fruit quality was not affected on different substrates. Similar studies produced similar results, showing that different substrates did not have any effect on fruit acid content or fruit quality (Godoi et al. 2009, Cantliffe et al. 2003).

7 CONCLUSIONS

In this study, we have determined the properties of wood shavings from different wood products as growing media for *Hosta* 'Golden Tiara' and strawberry 'Elsanta' plants. Possible toxic effects on horticultural plants (tomato and lettuce), water holding capacity and N immobilization of growing media have also been determined.

In phytotoxicity assays, tomato and lettuce germinated well on all of the substrates. WHC was high in Q, OA, and P50Q50. No nitrogen immobilization was found on Q-Treat, which is an advantage of Q-Treat when compared to other woody substrates. At the same time, EC and water content of the substrates were favourable for both *Hosta* 'Golden Tiara' and strawberry production.

For *Hosta* 'Golden Tiara', P50Q50 resulted in the highest leaf numbers in comparison to other substrates. However, *Hosta* plants grew well on all of the six soilless substrates that included wood, peat and combination of peat and wood substrates. As it is an ornamental plant, visual appearance is an important factor for *Hosta* 'Golden Tiara', and on visual observation, the plants grown on untreated wood-shavings were not satisfactory, whereas P50Q50 showing the best performance. Therefore, 50% of peat may be replaced by Q-Treat in soilless cultivation of *Hosta* 'Golden Tiara'.

For strawberry production, higher vegetative growth was found on peat, but berry yield was the highest on P25Q75 and peat. Moreover, less runner-formation was found on P25Q75, which is an an advantage to growers. Regarding the berry quality, wood substrates performed equally to peat. Taking into account yield, berry quality and low runner-production, 75% peat could be replaced by Q-Treat on soillless strawberry production.

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